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**THE DYNAMICS OF NAVAL SHIPBUILDING -  
A SYSTEMS APPROACH**

by

Timothy P. McCue

//

BA Physics, College of Holy Cross  
Master of Science in Mechanical Engineering, SUNY Stonybrook

Submitted to the Department of Ocean Engineering  
in Partial Fulfillment of the Requirements for the Degrees of

NAVAL ENGINEER

and

MASTER OF SCIENCE in OCEAN SYSTEMS MANAGEMENT

at the  
Massachusetts Institute of Technology  
June 1997

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*This thesis is dedicated to the*

*grandfather I never knew*

*LCDR Eugene Patrick McCue USNR*

## **Acknowledgments:**

Many people at many different levels contributed to this work. I was able to travel all over the country collecting information and interviewing people involved with Naval Ship Acquisition and Construction. From the LPD-17 Program Manager to the production planners at NASSCO to the manager of the Hardings plant at BIW, I found everyone to be passionate about what they do. I also found everyone willing to discuss new ideas and to try to find ways to improve the process. Without these discussions, the Ship Production Model would never have been created.

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# **The Dynamics of Naval Shipbuilding: A Systems Approach to Project Management Assessment**

by

Timothy P. McCue

Submitted to the Department of Ocean Engineering  
in Partial Fulfillment of the Requirements for the Degrees of

NAVAL ENGINEER and MASTER OF SCIENCE in Ocean Systems Management

May 1997

## **Abstract:**

Project management in the shipbuilding industry is a complex and misunderstood field. Ship programs are often delivered behind schedule and over budget. Many external factors can cause a relatively well run program to experience problems. These include material shortages, labor problems or customer generated design changes. Even harder for a manager to understand are internally generated problems from sources like overtime use, hiring and firing policy, and cost estimating.

Project managers do not understand or have the tools to measure many of the dynamic features of a construction process. These features include feedback, time delays and nonlinear cause and effect relationships among project components. In general, people have a hard time dealing with nonlinear relationships in their mental models of the world. When three or four of these relationships are operating at the same time, the resulting complexity becomes very hard to unravel intuitively. Experienced program managers can describe dynamics and understand they are operating on the system. They cannot quantify the strength or impact of these features on their project.

The purpose of this paper is to use System Dynamics modeling to examine the Navy Ship Acquisition and Construction process and to increase the knowledge and understanding concerning the management of large Navy shipbuilding projects. System Dynamics captures the many complex facets of ship construction simultaneously and examines their behavior over time. Using simulation, project managers in the Navy and in the private sector can make better, more quantitative decisions.

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# Chapter 1

## **1.1 - Introduction:**

The Naval shipbuilding industry is a complex and misunderstood field. Projects are typically behind schedule and over budget. Many external factors can cause a relatively well run program to experience problems. These include material shortages, labor problems or customer generated design changes. Even harder for a manager to understand are internally generated problems from sources like overtime use, hiring and firing policy, and cost estimating. Project managers do not understand or have the tools to measure many of the dynamic features of a construction process. These features include feedback, time delays and nonlinear cause and effect relationships among project components.<sup>1</sup> In general, people have a hard time dealing with nonlinear relationships in their mental models of the world. When three or four of these relationships are operating at the same time, the resulting complexity becomes very hard to unravel intuitively. Experienced program managers can describe dynamics and understand they are operating on the system. They cannot quantify the strength or impact of these features on their project.

The nature of the product also adds to the project's complexity. A ship is built from a multitude of small manufactured parts that are assembled into larger parts and finally fit together as construction blocks. If the small assemblies are not built to proper

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<sup>1</sup> Ford, D. N., (1995), *The Dynamics of Project Management: An Investigation of the Impacts of Project Process and Coordination on Performance*. Ph.D. Thesis. Sloan School of Management. Massachusetts Institute of Technology. Cambridge, MA.

tolerances, errors compound downstream to cause rework or out of sequence work. The precedence relationships of one phase of the project on another can lead to large delay and disruption penalties. If an error occurs in the design of the ship, it may not be discovered until many of the small assemblies have been manufactured. If the required design change is large enough, many of the smaller assemblies may be rendered obsolete. The results of such behavior include huge cost over runs, schedule slippage and poor customer relations.

Much work is ongoing to better define the product with 3-D product models. All new Navy ship programs require an electronic version of the ship that can be transferred from the government to the shipyard and back. Not much has been done in modeling and simulating the process by which ships are built. The real improvements that can be made in reducing the costs of Navy ships will come through process improvement, not through product optimization. By taking into account necessary process changes in product design, significant improvements in productivity can be realized.

The market for America's shipbuilders has gone from bad to worse in the last few years. Foreign competition has eroded the commercial industrial base. The US Navy is in a period of consolidation, limiting the amount of available government shipbuilding contracts. The lack of new work has made project management even more critical to shipbuilders. Problems with an existing project could cause the loss of future work with a valuable customer. Many major shipbuilders are experimenting to find new ways to improve the process in order to compete at home and abroad. The ship construction cycle

can take five to fifteen years. The process starts with initial concept design and ends with delivery to the customer. Cycle time reductions are critical in order to deliver a ship that meets an existing market or threat.

Much time and effort has been expended trying to revitalize the ship building industry in this country. A strong ship building industry allows the Navy to take advantage of state of the art commercial practices. The best practices of a market leader will result in reduced costs for Navy ships. Without a strong commercial base, the Navy must shoulder the cost and risk of developing any new technology. This is an expensive proposition. Perhaps the time has come to take a fresh look at the shipbuilding process. Business as usual clearly is not working.

The purpose of this paper is to use System Dynamics modeling to examine the Navy Ship Acquisition and Construction process and to increase the knowledge and understanding concerning the performance of large Navy shipbuilding projects. A glossary of terms is included in Appendix C to decipher the acronyms and unique terminology of shipbuilding. Likewise, System Dynamics is used to capture the many complex inter-relationships of ship construction simultaneously and examines their behavior over time. Jay Forrester developed the field in the early sixties to study complex social systems. System Dynamics has expanded in recent years to study product development processes in the software and automobile industries. Shipbuilding consists of large, complex, capital intense projects. Shipbuilders consider prototyping too expensive. Because of this, shipbuilding is a natural field for use of simulation.

Any large scale construction project demonstrates the following characteristics:

- Extremely complex, consisting of multiple interdependent components
- Highly dynamic
- Involve multiple feedback processes
- Involve nonlinear relationships
- Utilize “hard” and “soft” data<sup>2</sup>

All of these factors complicate the management of these projects. Shipbuilding has been the focus of several earlier System Dynamics studies. The most widely known cases involve litigation against the government. Potential exists for wider use of simulation in this field. Some proposed uses include:

- Contract Bid Analysis
- Productivity Improvements
- Optimal Manning Analysis
- Build vs. Buy Studies
- Policy Assessment
- Design Change Assessment and Management
- Cost Estimation

In this paper, computer simulation is used to investigate some of the management policies and constraints found in a shipyard. By combining these management policies,

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<sup>2</sup> Sterman, J.D., (1992), “System Dynamics Modeling for Project Management,” unpublished working paper, Systems Dynamics Group. Sloan School of Management. Massachusetts Institute of Technology.

shipyard constraints and the products characteristics in one model, the cumulative effect of all decisions a shipbuilder makes concerning a ship program can be examined. A computer model requires the user to define boundaries and make assumptions concerning the level of aggregation. The definition of boundaries narrows the scope of the model and makes clear to the user the purpose and limits of the model.

## **1.2 Motivation**

The US Navy manages some of the most complex and expensive projects in the country. The weapon systems, ships and aircraft produced in these projects are the most capable in the world. Problems inevitably arise in managing these high risk programs that produce cutting edge, state of the art hardware. Operating with risk is better understood in the commercial sector. Investing in new technology is a risky proposition and must be managed accordingly. Many innovators never take their product to market.<sup>3</sup> The inventor who introduces a new technology is often overtaken and forced out of business by a later entry competitor. Sometimes it is easier to let the competition develop a new risky technology. Once a dominant design is established the risks involved decrease. Small improvements in the product and the manufacturing process provide a competitive advantage. In this way, one could develop a competitive product without being exposed to large risks.

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<sup>3</sup> Utterback, J.M., (1994), *Mastering the Dynamics of Innovation*, Harvard Business School Press, Boston, MA.

This is not an option for the US Navy. The United States has long relied on a commitment to using the latest technology in our military hardware as a tactical advantage. Allowing the enemy to take the lead in developing new weapon systems could have dire consequences for the Navy. Experiences in the Gulf War indicate that technology can be effectively used as a force multiplier.

The Department of Defense has had significant problems integrating new technology into existing product lines in an expeditious and affordable manner. Technology integration has become even more critical in the last few years with the rapid development of information systems, computational capability, and global inter-connectivity. To maintain our technological advantage we must do things smarter, cheaper, and faster than the enemy.

Computer hardware frequently becomes obsolete in less than 5 years. This forces a similar reduction in military product development times. Current cycle times for Navy ships from concept design to final delivery may take as long as fifteen years. During this period of time the entire world may have changed. Just such a scenario occurred with the Seawolf class submarine. The Seawolf was designed at the height of the Cold War to be the most capable attack submarine in the world. Its primary mission was to attack Russian submarines. In the time it took to design and build the Seawolf, the Russian Navy virtually collapsed. The threat the Seawolf was built to meet no longer exists. This left the Navy with a very capable, and expensive, ship with no legitimate adversary. Most of the class

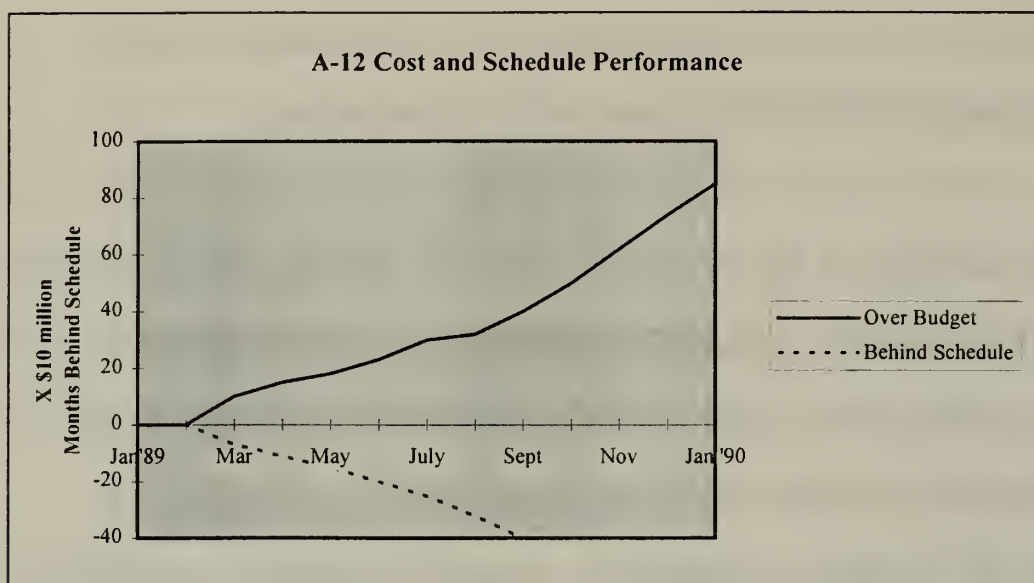
was canceled as a result. Cycle time reductions are a critical improvement the Navy must make in order to match hardware with current requirements.

For the military, failing to utilize a critical technology could mean the difference between winning the next battle and not coming home! For the private sector, the situation is very similar. Missing a jump in technology could mean loss of market share and could drive the company to bankruptcy. The stakes in both cases are very high. A recent study conducted to benchmark product development projects around the world indicates that less than fifty percent meet their targets for cost and schedule.<sup>4</sup> Clearly something is acting to mislead planners and managers as to the real cost and schedule needed to develop new products.

The latest and most expensive case of mismanagement of a military program is the new attack aircraft designated the A-12. Although many people involved with this program were aware of serious problems with weight and schedule, the project was allowed to continue. The performance for cost and schedule demonstrates exponential behavior as can be see in Figure 1-1.

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<sup>4</sup> Roberts, E.B., (1992) "Strategic Management of Technology: Global Benchmarking," Cambridge MA



**Figure 1-1 A-12 Cost and Schedule Performance**

The managers of this program chose to quibble about specific ceilings and scheduled dates instead of looking at the behavior of the project. Clearly, the project was out of control early in 1989 when overruns reached \$100 million dollars. By March of 1990, it was estimated to be more than \$1 billion dollars over budget and 1 year behind schedule. The contractor team of General Dynamics and MacDonald Douglas, the Navy management team, and the Congressional Oversight Group all were using different models to predict program performance. The program was eventually canceled resulting in a huge loss of taxpayer's dollars, new capability for the Navy's attack aircraft component and million of dollars in revenues for the contractor team. The law suit as to who is responsible for the brunt of the losses is still in litigation.<sup>5</sup>

<sup>5</sup> Beach, C.B., (1990) "A-12 Administrative Inquiry", Memorandum for the Secretary of the Navy.

Why, with the stakes so high and the talent available, do these problems occur? What are the underlying causes for the cost and schedule overruns experienced in large military development projects? Why are cost and schedule estimating tools so bad at predicting what would really happen given a set of conditions? Are there policies that can be used to address dynamic sets of circumstances which result in better project performance? These are all questions that will be addressed in this work.

### **1.3 Outline**

A literature search is conducted to determine the current state of the Navy ship acquisition process. The affordability crisis the Navy is currently experiencing in acquiring the new ships it needs is examined. Hypotheses on how to improve the process will be generated and discussed for applicability.

Several current acquisition reform measures instituted by the Department of Defense aimed at improving the process including Affordability Through Commonality (ATC) and Commercial Off The Shelf (COTS) will be reviewed for their impact on the crisis.

The National Shipbuilding Research Program (NSRP) is one of several projects which study ways to improve the competitiveness of US shipyards. Part of the NSRP approach is to encourage the development of a Build Strategy for

each yard. A Build Strategy consists of all of the important decisions a builder and a customer must make in order to build a ship. If the Build Strategy is well thought out, the program has a better chance of success. Build Strategy development is discussed and a plan is formulated for a high performance commercial ship. Key events are identified. Block breaks and construction sequence are discussed. The different stages through which the parts that make up the ship are discussed.

A series of shipyard visits is conducted to observe US Navy ship building in commercial yards. The different sequences used for building ships and the critical features of managing these projects are discussed. Several hard to quantify variables like quality, productivity, and rework are discussed with shipbuilders. The shipyards include:

- Avondale Industries, New Orleans, LA
- Bath Iron Works, Bath, ME
- Ingalls Shipbuilding, Pascagoula, MI
- NASSCO, San Diego, CA

In many cases the perspective of a program manager is formed by the tools used to measure performance. Without robust tools that can capture the important factors of a project, a manager will be operating with an incomplete picture. Current tools used to manage Navy projects and develop cost estimates are

discussed. The advantages and disadvantages of the current tools are reviewed. One management field that has received little attention from the Navy is System Dynamics. Dynamic models have been used in the past by contractors to describe the shipbuilding process in support of delay and disruption claims against the government. Although System Dynamics was used successfully by shipbuilders to demonstrate their case, the Navy chose not to develop any of their own models.

A dynamic model, the Ship Production Model, is developed and examined in detail to determine its applicability to Navy ship construction. The observations and data collected during the shipyard visits are used to develop the structure and policies found in the model. The model's purpose and boundaries are discussed. The structure of the dynamic sectors of the model are examined in detail.

The Ship Production Model is used to determine the best way to build a new ship in a virtual shipyard. Several policies are examined including: quality, use of overtime, and required manning levels. Analysis is conducted to determine the choke point in the process. Infrastructure is added to determine its impact on the performance of the project.

The model is tuned to exhibit the features of existing shipyards. A comparison of two shipyards is conducted on a high performance commercial ship program. Schedule and cost performance are evaluated. Several ways to improve the productivity of each yard are discussed.

Finally, the implications for future use of Systems Dynamics in Navy program management are discussed. Dynamic models become the reservoir of much information about the system. The real value of the model is the chance to examine policies in detail rapidly and without risk to the program. The models become valuable communications tools that can be used to find common ground between the government and the contractor on difficult issues. Models could be used as early as the concept design stage to make clear the goals and objectives of all interested parties. By providing a tool to practice the management of a large project, problems like those experienced on the A-12 can be avoided.

## Chapter 2 - Literature Search

In this chapter, a review of the literature is conducted to determine the current state of the Navy ship construction process. The cost of buying Navy ships has increased steadily in the past 20 years. The dynamics behind this increase will be investigated using causal loops. Several initiatives that attempt to remediate this problem will be investigated including acquisition reform, revitalizing the commercial industrial base, and build strategy development. Possible solutions to this Affordability Crisis are discussed. These include Lean Shipbuilding. Finally, the use of System Dynamics modeling is discussed as a way to better understand the complexities of shipbuilding and to examine the true impact of some of the reform measures.

### ***2.1 The Affordability Crisis***

The Navy is currently experiencing a crisis in which it can no longer afford the ships it requires. Several acquisition reform programs including Affordability Through Commonality (ATC), Commercial Off The Shelf (COTS), and Standards and Specification Reform have been developed to address this crisis. These are described in detail in the next section. Some of these programs may have a real impact on the cost of future ships. Others are merely first aid to correct a small but visible problem.

Several programs have also been instituted to try to revitalize commercial shipbuilding in this country. These include the MARITECH Program, National Shipbuilding and Research Program (NSRP), and Mid-Term Sealift Ship Technology

Development Program (MTSSTDP). These efforts study why the commercial shipbuilding industrial base has eroded since 1980 and attempt to find corrective measures. They also try to show US shipbuilders how they can become world class manufacturers. Foreign shipbuilders can produce ships faster and cheaper than their American counterparts. Without throughput to improve shipbuilding methods and productivity, American yards will continue to lag behind foreign yards when competing for commercial contracts. Either more Navy work needs to be generated or commercial work needs to be stimulated in some way.

It is critical to understand the true nature of the Affordability Crisis before attempting to repair it. In some cases, two acquisition reform programs are in conflict with each other. Although each measure sounds like a good idea on paper, each must be tested for applicability in real life amidst the complexities of the process. The dynamic, non-linear nature of the ship construction and acquisition process is difficult to grasp. Because of this, some solutions address one part of the crisis while ignoring the big picture. Applying solutions that do not take into account the entire problem may have a detrimental effect instead of the desired positive effect. Causal loop diagrams are used to try to capture some of the dynamic behavior that is described but not explicitly defined by other authors. Many articles discuss pieces of the crisis but few capture the whole picture. Without a broader perspective, true acquisition reform is not possible.

## 2.11 Reference Modes

The process used to develop a System Dynamics model involves:

- Reference Mode Identification
- Dynamic Hypothesis
- Modeling
- Analysis

These steps force the modeler to fully examine the system of interest. In many cases, valuable insight can be gained during each step in the process.<sup>6</sup> For the Affordability Crisis, the first two steps in the modeling effort will be conducted. To fully model and analyze the Affordability Crisis is beyond the scope of this work.

The first way to examine this problem is to look at historical data on a set of axes. From these plots, trends can be observed concerning the nature of the problem. These trends describe behavior of the important variables in the problem. The behavior will indicate whether a variable represents a problem or not. Is the variable exhibiting linear behavior or does it exhibit exponential behavior? Does the growth decay slowly to an upper limit or does it continue to infinity? Is the behavior cyclical? Much insight can be gained by examining the reference modes of a problem in this fashion. The first reference mode for the Affordability Crisis is demonstrated in Figure 2-2.

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<sup>6</sup> Hines, J.H. and Johnson, D.W., (1994), Launching System Dynamics, International System Dynamics Conference.

## Cost of Surface Combatants (\$K/Ton)

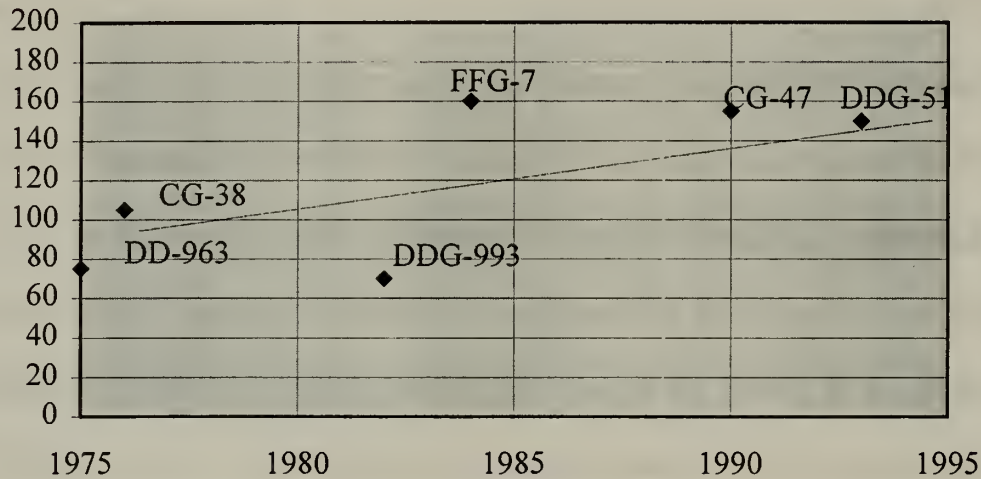


Figure 2-2 - Cost of Surface Combatant Ships in \$K (FY 90)/TON

The total acquisition cost in constant dollars of Navy surface combatant ships per ton is steadily increasing with time. The behavior associated with this trend is linearly increasing. These costs are the result of several inter-related dynamics.

First, more military capability is required to counter the threat of faster, deadlier, and more widely distributed advanced weapons systems. The military tends to incorporate new technology to a greater extent and is willing to assume more risk than commercial product development groups. To remain the technological leader of military hardware in the world, the Navy must pay “innovator” costs. In the commercial world, this role is called an industry leader. This position has its advantages and disadvantages. Being first to market allows you to grab market share from the competition if the new

product is superior. However, once a product has been brought to market, the competition has the luxury of reverse engineering to determine what went into the development effort. Sometimes it may be more cost efficient to follow the market leader with a similar product if the development effort is risky. Thus far the US military has committed itself to remaining an industry leader. The costs associated with this strategy must be understood and dealt with accordingly. This behavior will be described as the Arms Race dynamic.

Second, the decrease in Navy ship end strength numbers reduces new ship construction contracts. After a peak in 1990, the trend has been sharply downward. Several projections have been made concerning the future size of the Navy including the Surface Combatant Force Level Study and the Bottoms Up Review. Based on these studies, current national directives call for a force of between 325 and 350 ships for the foreseeable future. The current defense budget spending does not even support this level. As the worldwide threat changes, these levels will be adjusted accordingly.

The portion of the defense budget allocated to ship construction is around \$5 billion dollars per year. To support the current force levels at current costs, the required expenditures to maintain a 325 ship Navy is \$7.4 billion dollars as indicated in Table 2-1.

Ship Type	#/year	Service Life	Force Level	\$B/year
CG/DD	3	30	90	2.7
CV	0.2	50	10	0.9
A	1	30	30	0.5
SSN	1	30	30	1.5
SSBN	0.5	30	15	1
AMPHIBS	2	25	50	0.8
Totals			225	7.4

Table 2-1 - Force Levels and Expenditures

With fewer ships being built, volume discounts associated with long production runs are not achieved. The unit cost of doing business increases since there is less business over which to spread overhead costs. This behavior will be further discussed in the Military Industrial Base diagram. Figure 2-3 shows the trend for the number of ships on active duty in the Navy.

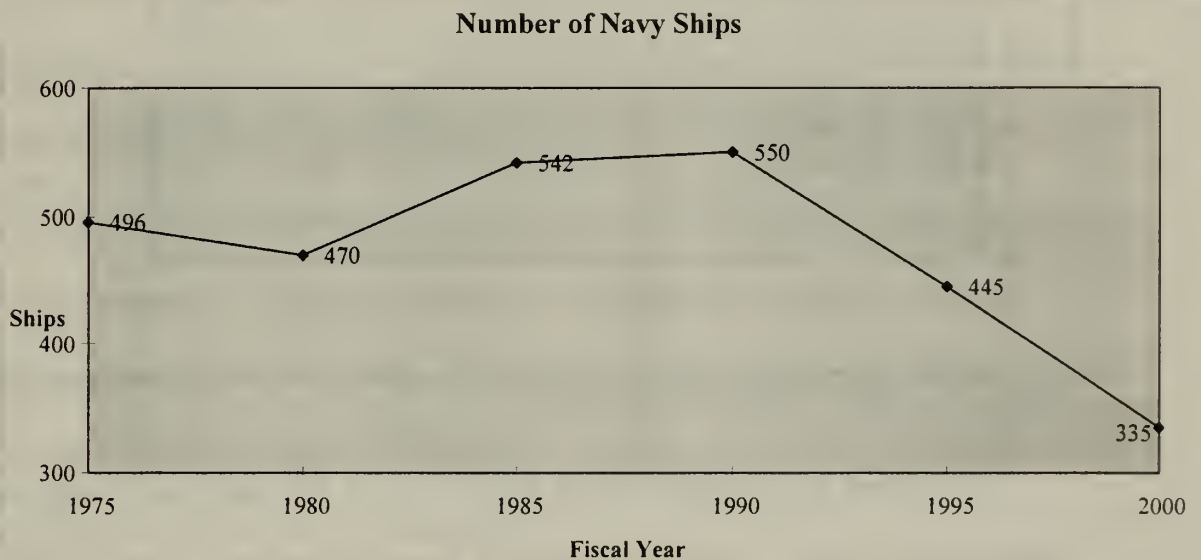


Figure 2-3 - Size of the US Navy

Third, the Navy's support infrastructure is harder to downsize than number of ships. This results in higher cost of support infrastructure until adjustments can be made through the Base Realignment and Closure program (BRAC). This dynamic will also be discussed in Military Industrial Base.

The commercial shipbuilding industry in the United States has been in decline for some time. The reference mode for this is demonstrated in Figure 2-4.

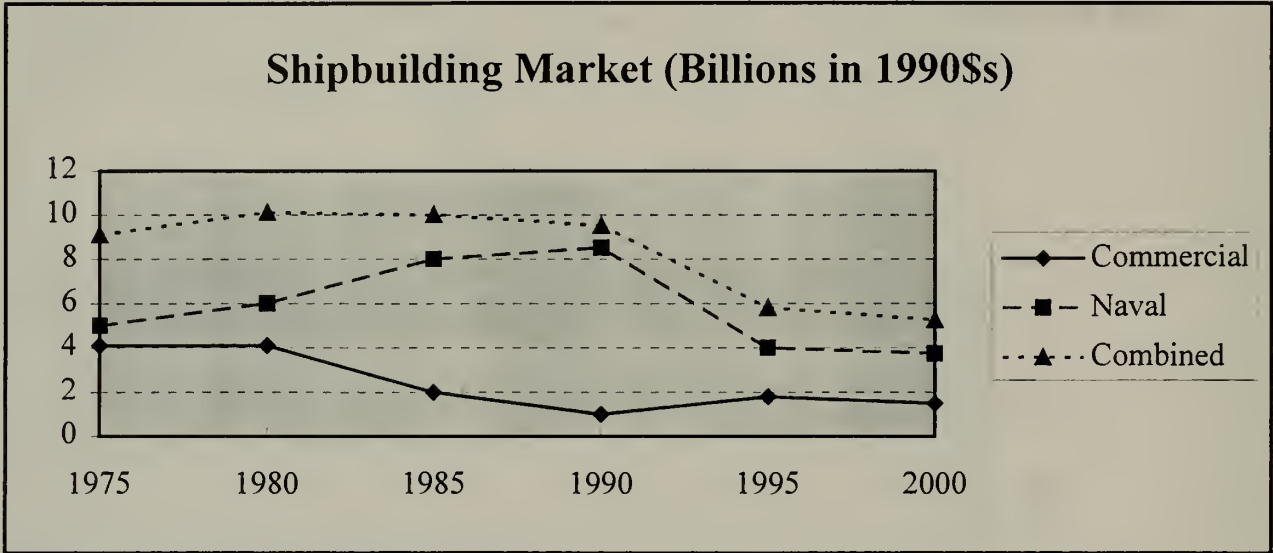


Figure 2-4 - Domestic Shipbuilding Market

This trend was obscured during the push for a 600 ship Navy in the military buildup of the 1980's. The Japanese and the Koreans continue to capture most of the market share of new construction commercial shipping. If the Navy is to ever realize lower costs for their ships, the domestic shipbuilders will need to update their

shipbuilding methods to the level of the competition. If US yards could capture a reasonable portion of the commercial market, valuable experience could be gained in modern production methods. The modern techniques used by world class shipyards would result in decreasing the cost of producing Navy ships.

With the paltry share of the market enjoyed by American Shipyards, currently 1.2 %, the required improvements in shipbuilding technology will not occur without government subsidies. No commercial base exists to provide the economies of scale necessary to stimulate improvement. In the automotive and aerospace industries, great strides have been made to improve American competitiveness on a global basis. Without a healthy commercial industrial base, shipbuilding in this country will never become world class. It is quite apparent by examining the order book of American shipyards today in Figure 2-5 that we are not competitive.<sup>7</sup>

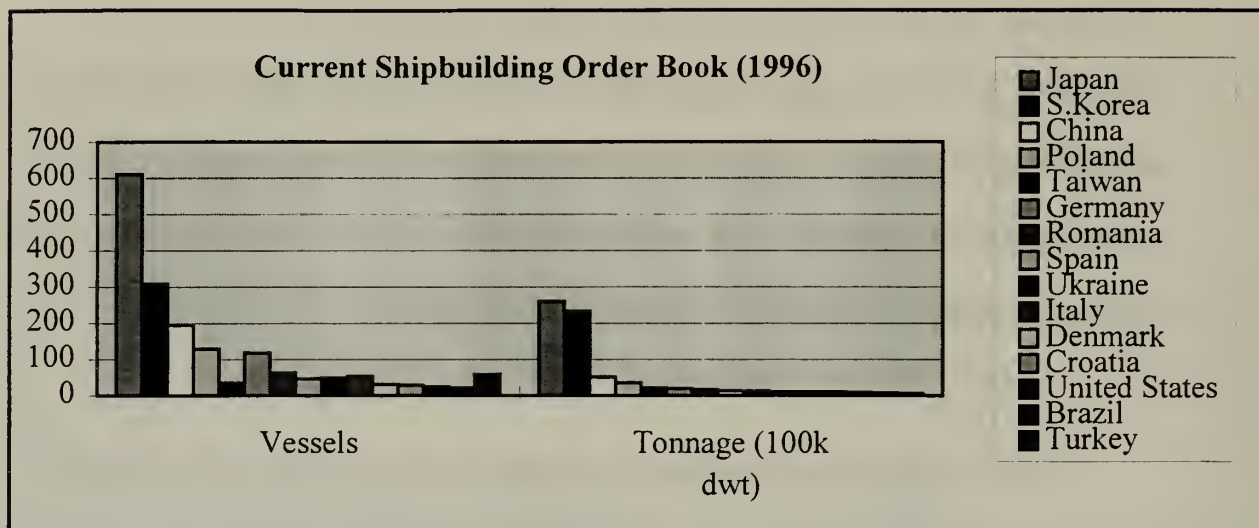


Figure 2-5 - Shipbuilding Trends

If the commercial base continues in its present state of decline, the Navy will be faced with a monopsony in which only one customer exists in a given market. DOD acquisition regulations require competitively bid contracts. With the few number of new ships currently being built and more importantly, the meager amount of ships planned for the next 20 years, private shipyards may not have the work to stay in business. In order to maintain the industrial base, the Navy has been forced to pay an exorbitant amount for each new ship. This behavior is defined further in the Commercial Industrial Base diagram.

Finally, the level of uncertainty in the basic national objectives adds to cost of doing business. The proliferation of advanced technologies make staying ahead of the game a very expensive proposition. During the Cold War, the huge expenditures needed to maintain our technological edge were justified as a national priority. In the post Cold War era, the threats to our interests are not as well defined. Without a clear threat, the

justification for new expenditures is not as apparent. For this reason, specialized ships that are built to counter specific threats look less attractive. “Future uncertainties establish an increased value and need for flexibility on operational usage.”<sup>8</sup> This changes the emphasis for ship designers. To deal with uncertainty, they need to design in flexibility or margin for future upgrades. Instead of optimizing the ship for a specific mission, the design margin allows for growth or new weapons packages in the future.

## 2.12 Definition of Terms

The next step in examining the problem is to define the important variables associated with Navy ship construction and acquisition. Once the variables are identified, they can be grouped by their relation to each other. A brief description of how they change over time is included. These variables involved with the Affordability Crisis were gleaned from literature and interviews with shipbuilders and Navy program managers.

### Arms Race Dynamic

*Advanced Weapons Proliferation* - The rate at which high tech weapons spread to other nations. Today’s world is characterized by little if no real threat to US Interests. For this reason, the leading arms exporter in the world has become the United States. The rate at which advanced weapons proliferates to the Third World is faster than ever before.

*Actual Threat* - Advanced weapons in the hands of countries or individuals at political or economic odds with the objective of the United States.

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<sup>8</sup>Bosworth, M. L. and Hough, J. J. (1993). Improvements in Ship Affordability. The Society of Naval Architects and Marine Engineers Centennial Meeting.

*Perceived Threat* - Based on intelligence sources. Currently perceived to be low. The perceived threat drives the commitment of funds to the military. If the perceived threat is low, fewer dollars allocated to the military. The problem with the Perceived Threat is that it takes time to formulate. It is also subject to the biases of the analyst. Several times in recent history, the United States has found itself caught looking the other way because the Perceived Threat was wrong.

*Required Military Capability of US Ships* - The number of ships, aircraft and missiles needed to carry out the missions tasked by higher authority. Current tasking calls for the ability to fight two Major Regional Conflicts simultaneously. As force levels drop, this requirement may need to be revised.

*Cost of Navy Ships* - The acquisition cost of Navy ships. The material, labor, and shipyard overhead costs that make up the purchase price of a Navy ship.

*Pressure for Reciprocating Capability* - The pressure for countries at odds with US objectives to match the technology and weapons of the US

## **Military Industrial Base**

*Navy Order Book* - The amount of work the shipyards have on order generated by the Navy. Consists of new construction, conversion or maintenance. In the eighties the total Navy Order Book came close to twenty billion dollars a year.<sup>9</sup> In the leaner times of the nineties, the Order Book is more like six or seven billion dollars.

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<sup>9</sup> On the Rebound? Navy Business, Marine Reporter and Engineering News, February 1997.

*Need for New Ships* - There are several things that drive the need for new ships. First, older ships need to be replaced as they reach the end of their service lives. New ships may also be needed to meet a new threat. This was the case of the Mine Hunters built in the early nineties. Finally, in time of war, ships need to be built to replace damaged or lost ships. The current need for new ships is low. More ships will leave the Navy this year than will be commissioned.

*Defense Budget* - The amount of money committed each year to supporting the military. Part of this is committed to Ship Construction, Navy (SCN), the portion that goes to building new ships. Current defense spending is lower than it has been since the seventies.

*Required Military Capability* - The ability to carry out the objectives of higher authority against a given threat. As the enemy capability rises, the Required Military Capability Rises as well.

*Capability Gap* - The gap between the existing capability of the Navy and the capability required to achieve the objectives outlined by higher authority.

*US Shipyard Overhead Rate* - The rate charged to a ship contract that covers the infrastructure and management costs of the shipyard. If the yard has very little work, these charges have to be absorbed over a smaller revenue base. This drives the overhead charges up for any one contract.

## **Commercial Industrial Base**

*Foreign Productivity* - The ability of foreign yards to produce ships measured in tons/person/year. The productivity of foreign shipbuilders, in particular the Japanese, is

considerably higher than typical US workers on similar projects. The reasons for this difference will be discussed in a later section.

*US Productivity* - The ability of American shipbuilders to produce ships measured in tons/person/year.

*Foreign Order Book* - The amount of work, measured in dollars, that a shipyard has under contract. A large order book means the future will remain stable. It allows investments in personnel, infrastructure and process improvements.

*US Commercial Order Book* - The amount of work American yards have under contract.

*Foreign Construction Costs* - The total acquisition cost to the ship buyer in a foreign yard.

*US Construction Costs* - The total acquisition cost to the ship buyer in a domestic yard. The cost of buying ships in this country has grown to almost double what a similar ship would cost overseas.

*Foreign Subsidies* - Many foreign countries offer construction subsidies to shipyards. This acts to reduce the cost to the shipowner of buying a ship in that country. Stimulating heavy industry in these countries is a national priority.

*US Subsidies* - In 1980, the United States government eliminated the Construction Differential Subsidy (CDS) which was designed to keep American shipyards competitive in the world shipbuilding market. The commercial shipbuilding base has been in decline since this time. Under the Clinton Administrations National Shipbuilding Initiative (NSI), other forms of subsidies have been explored. These include NSRP studies, MARITECH funding for new ship designs, and Title XI financing and guaranteed loans

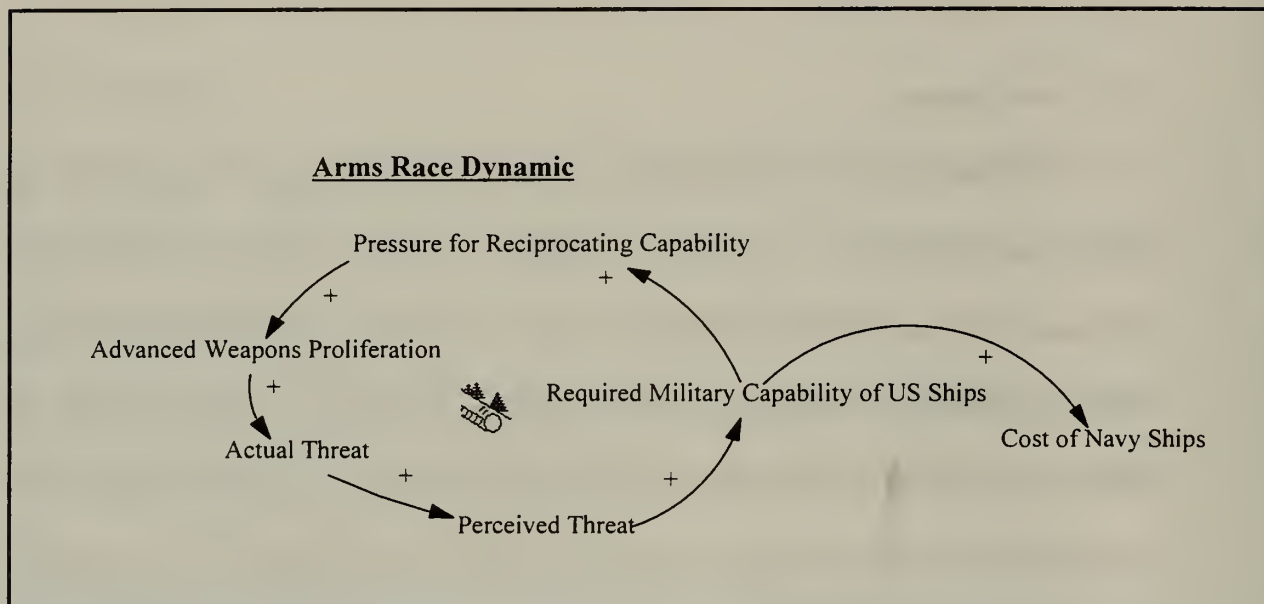
for new ships and for investments in infrastructure to try to make the US shipyards more competitive.

### **2.13 Causal Loops**

The final step is to build causal loops that link the variables. In this way the relationships between the variables can be shown. A polarity is assigned to the arrows that connect the variables. If the polarity is positive, the two variables behave in the same way. If the polarity is negative, the two variables act reciprocally. If one increases, the other decreases. The loops created can be either balancing or reinforcing loops. These are designated by either a balancing scale or a snow ball rolling down hill respectively. Three separate dynamic relationships act to increase the cost of Navy ships. Determining the strength of these loops will require more research. Understanding that more than one force is acting at any time is critical to solving the problem.

The first loop modeled is the Arms Race Dynamic depicted in Figure 2-6. The Actual Threat of armed conflict in the world positively affects the Perceived Threat with a time delay. The Perceived Threat is a combination of intelligence and strategic national objectives. Based on this Perceived Threat, the Required Military Capability of US Ships to meet the threat is developed. This capability consists of a combination of platforms which can carry out various missions. The actual capabilities required are better defined if the perceived threat is well understood. If the perceived threat is not as well defined, the platforms that are used to meet this threat need to have multi-mission capabilities or be reconfigurable. As the Perceived Threat increases, the Required

Military Capability of US Ships also increases. As more capability is required, the level of technology needed to respond tends to increase with a subsequent increase in cost.

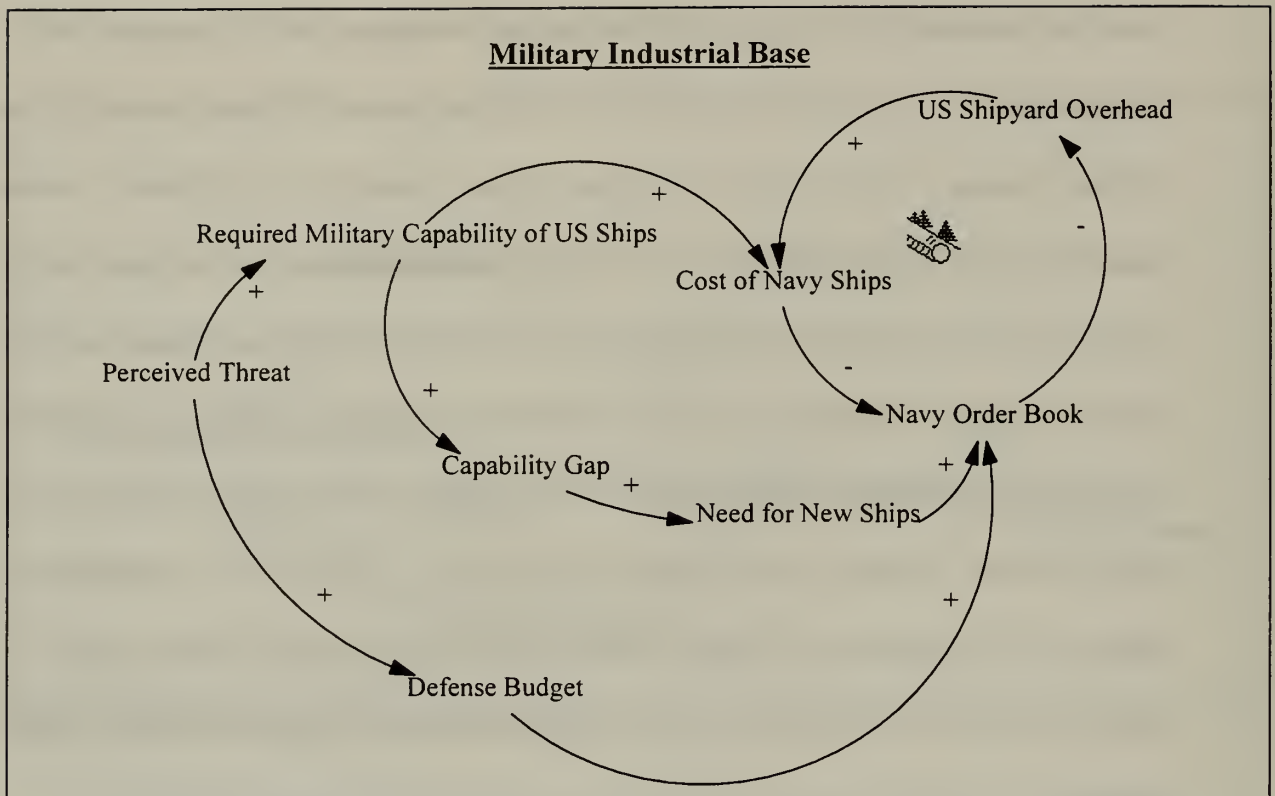


**Figure 2-6 - Arms Race Dynamic**

The dynamic part of the arms race is that as the current capability of US Ships increases, the level of technology needed to match this capability increases. Pressure for Reciprocating Capability is placed on other world powers to match this new capability with a time delay. This pressure tends to increase the rate of Advanced Weapons Proliferation. In turn, weapons proliferation increases the Actual Threat to US objectives. This completes a reinforcing feedback loop that has been the topic of much discussion since the beginning of warfare. The Arms Race Dynamic has been the cause of many wars including World War I and has resulted in the expenditure of countless dollars. Defusing this reinforcing feedback loop has proven to be a huge challenge.

The next loop, the Military Industrial Base Dynamic shown in Figure 2-7, deals with the decreasing level of the US fleet and the subsequent loss of business for US Shipbuilders. The Perceived Threat directly affects the amount of money allotted to the Defense Budget. It also affects the Required Military Capability of US Ships. As was seen directly after the Persian Gulf War, without a legitimate threat, the Congress looks to reduce the money expended on the military. The funding for additional defense spending usually evaporates long before the Required Military Capability of US Ships is adjusted. The problem is that these Defense Budget cuts are based on the Perceived Threat, not the Actual Threat. If deep cuts in capability are made too rapidly, it is impossible to regenerate this capability in a timely fashion should the Perceived Threat change. In some cases, contractors who make products exclusively for the military are forced out of business.

As the Perceived Threat decreases, the amount of money dedicated to the Defense Budget decreases. The Navy Order Book for new construction and for service life extensions is correspondingly reduced. As the amount of work the Navy orders from the shipyards decreases, the US Shipyard Overhead increases. Overhead is the amount of money that is charged to a contract to cover the costs of shipyard infrastructure. As the work decreases, the overhead is spread out over fewer projects thus increasing the cost of each contract. As the US Shipyard Overhead increases, the Cost of Navy Ships also increases. As the Cost of Navy Ships increases, the number of ships the Navy can buy for the allocated money decreases. This, in turn reduces the Navy Order Book resulting in another reinforcing feedback loop.



**Figure 2-7 - Military Industrial Base**

The final loop, shown in Figure 2-8 deals with a problem that has been developing in this country since 1980, the Commercial Shipbuilding Industrial Base. When the US government decided to cut the Construction Differential Subsidy (CDS), US Shipbuilders could no longer compete with their overseas competition for commercial ship contracts. Looking at the diagram, as US Subsidies decrease, US Construction Costs increase. This tends to increase the cost differential between US and Foreign Construction Costs. As the cost differential increases, the US Commercial Order Book decreases and the Foreign Order Book increases. As the Commercial Order Book decreases, the US Shipyard Overhead rate increases resulting in higher costs for Navy ships. The distressing part of this diagram is that as the US Commercial Order Book decreases, US Productivity also

decreases. The ability to keep up with state of the art shipbuilding practices requires work on which to learn these skills.

A quick look at the reference modes indicates the US Commercial Order Book has been practically non existent for the last 15 years. As US Productivity decreases, US Construction Costs continue to increase resulting in a reinforcing loop. Contrarily, the Foreign Order Book has benefited from the cost differential. As more work has gone overseas to the Japanese and the Koreans, their productivity has greatly improved. The ability to practice modern shipbuilding techniques on commercial ships has provided the foreign yards with a huge advantage. Having more work in the yard allows the Foreign Overhead Rate to be spread over several contracts. As Foreign Productivity increases, Foreign Construction Costs continue to decrease resulting in another reinforcing feedback loop.

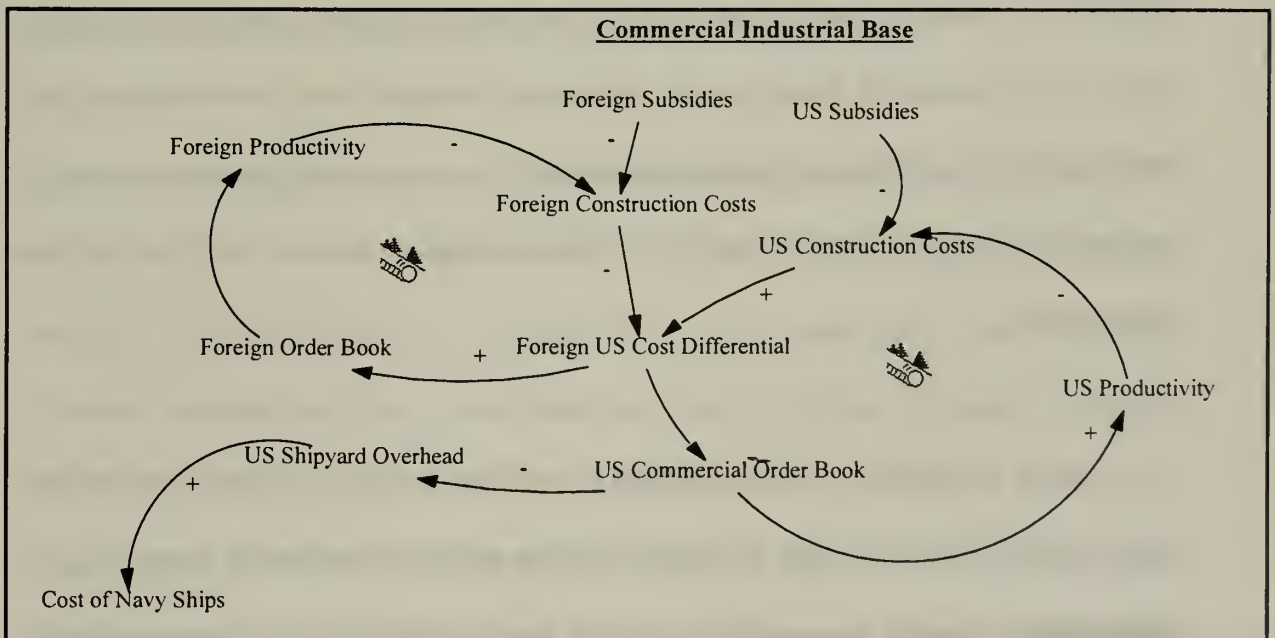


Figure 2-8 - Commercial Industrial Base

US shipbuilders are in a very difficult situation. As the military order book decreases, they have less business for which to compete. Without a significant order book, the future remains risky for many yards. Investments in yard improvements are put off until new contracts are signed. The productivity of American yards lags far behind the foreign yards. We employ more shipyard workers than any other nation in the world. Why then do we produce so few ships?

The improvements will come to US Productivity only if work can be generated on which to learn modern practices. The US government has chosen to provide assistance to the airline industry and the automotive industry at different times during the past twenty years. These decisions were made because these industries represent vital national interest. Similarly, the shipbuilding industry represents a vital national interest. The shipyards are now looking to the Japanese to help improve shipbuilding processes. An NSRP study identified several items as weaknesses in the way American yards build ships when compared to foreign yards. Technology transfers have been attempted with foreign yards to attempt to make up the shortfalls in new designs and technology. Instituting a change in the management of the construction process will take an even greater effort.

If the Affordability Crisis is allowed to continue, the Navy will not be able to buy the necessary hardware to meet its commitments or adequately protect its personnel. US Shipbuilders will not be competitive in the world market to win commercial ship

contracts. If they are forced to rely on the Navy as their sole customer several of the US yards may be forced to close by the year 2000.

Looking at all of the loops of the Affordability Crisis simultaneously, we see that there are many ways to reduce the cost of Navy ships. Not all of the of the variables involved in this problem have been discussed or even thought about. Some of these suggestions may not be realistic in today's political environment. We could, for instance, force the under utilized shipyards out of business by denying them Navy contracts. The yards that have work should be fully loaded with work to increase learning on the contracts available. The representatives to Congress from the states these yards are located may have a difficult time letting a major industry, like shipbuilding, with many well paying jobs leave their state. Congressmen have terms of 2 years. The real benefit of reducing under utilized shipbuilding capacity will not be realized on a national for several years after the closing. It may never be felt on the local level.

Another suggestion could be to re-assess Navy commitments around the world. If we did not need to commit naval forces around the world, the required Military Capability of Navy Ships could be reduced. This would immediately reduce the amount of money we spend on ships. It would also act on the Arms Race Dynamic by reducing the Pressure for Reciprocating Capability. In the long term it may have the desired result of reducing the Actual Threat. The problem is that higher authority sets the commitments for the Navy. Reducing the international profile of our Navy may have the desired effect of reducing the amount of money we spend on ships. It may also indicate to leaders of

countries not so friendly to the US that the time has come to push their own national agenda.

The strength of each of the loops needs to be determined using historical data. It may be impossible for improvements in the Commercial Industrial Base loop to come anywhere near reducing the cost of combatant ships to a significant degree. The push for new technology may make this loop inconsequential. Is it more cost effective to subsidize the construction of commercial ships in this country hoping to reap some productivity gains or to directly invest in new technology for Navy ships? Many experts say building a warship is an entirely different process from building a commercial ship. By modeling the Affordability Crisis in greater detail, the insights needed to make good decisions about investments in Navy shipbuilding could be made. Without the tools to properly address all the aspects of shipbuilding, we may wastefully invest in the wrong loop.

Another suggestion that will be further pursued further in this paper is to fund the construction of high performance commercial ships directly. These ships are more similar to combatant ships in their construction than typical break bulk, container or product carriers. The government would fund the construction and then lease them to commercial shippers at market rates. The government will need to replace the aging Ready Reserve Fleet in the next ten years anyway. Why not make these ships commercially viable? The Department of Defense could use these commercial ships as Sealift assets in time of war. Commercial ship operators could use the superior capability

of these ships in peacetime. The increased Commercial Order Book would stimulate increases in US Shipyard Productivity. It would also act to reduce US Shipyard Overhead. Both of these would act to eventually reduce the cost of building Navy ships.

The time has come to make smarter use of government assets concerning US Shipbuilding. Several initiatives are underway in the Navy to improve the acquisition process. More must be done than merely putting band aids on the problem. An entirely new way of doing business must be pursued if US Shipbuilders are to reclaim a market in which they once dominated. In the next section, several acquisition reform programs will be discussed. The initiatives aimed at stimulating commercial shipbuilding in this country including MARITECH, NSRP and the Mid Term Sealift Technology Development Program will also be reviewed in the context of the Affordability Crisis. Questions that should be asked include what loops do these programs effect and what is the magnitude of the contribution they will make? By taking a more systematic approach, we can look at these programs from a different perspective.

## ***2.2 Acquisition Reform***

The goal of Acquisition Reform is cost reduction through adoption of best commercial practices and streamlining advanced technology insertion. The process of building a ship for the Navy is vastly different from building a commercial ship. Additionally, the product development cycle time of a Navy ship (10-15 years) can be two to three times the period required to develop a new commercial ship design.

Determining what technology will go into a ship 15 years in the future is an incredibly risky task. The product development process and the cycle time must change if the Navy wants to reduce the cost of buying ships. In order for the US Navy to take advantage of best commercial practices, a viable commercial industrial base needs to exist.

This section examines several of the acquisition reform programs, COTS and Standards and Specifications Reform, and the ATC program. These programs will then be viewed in the context of the Affordability Crisis to determine which dynamic loop they affect.

## **2.21 - Commercial Off The Shelf (COTS)**

The Cold War forced the military to push for better and better technology at any expense. Huge amounts of money were expended to develop the technology that would allow the US military to maintain a tactical advantage. To address specific military requirements for products a system of Military Specifications and Standards (MILSPEC and MILSTD) were developed. The standards ensured the product met all requirements of the military. Many commercial applications grew out of this Defense initiated research program. In many cases, the commercial applications became more capable and less expensive as they went through several generations of product development in the private sector.

In the past few years, the technology trend has reversed itself for many products. For example, the military no longer drives the push for smaller electronic components or

faster microprocessors. Commercial products are demanding faster data transfer rates and more computing power than most military applications. The Navy, however, has been stuck with the requirements of a MILSPEC product that may be less capable and cost much more than the commercial product. The COTS program calls for increased use of commercially available equipment. This allows the Navy to take advantage of the cost savings from new technologies developed in the private sector. Clearly all the needs of the Navy can not be met by the commercial sector. Commercial products in general are not designed to go to war. However, as much of the common architecture as is feasibly possible should be bought “off the shelf.”

COTS will help to improve the Affordability Crisis. It reduces the cost of adding Required Military Capability. By choosing a commercially viable product, the cost of research and development associated with putting that piece of technology on a ship is greatly reduced. When upgrades are required, a standard commercial interface will usually allow a quick transition to the next version. For a military upgrade, the old system more times than not will need to be torn out and replaced with a new unit. By using more commercially available equipment, the development and acquisition costs of Navy ships will be reduced.

## **2.22 Standards and Specifications**

The Department of Defense has relied in the past on MILSPEC and MILSTD to describe exactly what it needs for a certain applications. Standards have been used to ensure the equipment meets all the rigors of a military environment. Many of the Standards and Specifications have been “written in blood” of sailors who relied on

substandard equipment. Every time an accident occurred, another specification was written to ensure it didn't happen again. Over the years, the number of different specifications has grown to a staggering level.

In the past few years, many of these specifications have become obsolete. The military industrial base to supply many of these parts has undergone significant downsizing as well. In many cases the Navy is faced with products that have a single or no supplier. The lack of competition for these products has allowed an increase in costs. Without a wider commercial base for these products, they become custom made for the military. One example is steel plate. Bath Iron Works is forced to buy MILSPEC DH-36 steel plate to use in the DDG-51. The steel suppliers will only produce this particular plate in large lots. This requires Bath to purchase all of its steel plate in one lot during the summer. The inventory then sits for up to a year before it is used. The cost of maintaining excess inventory has become a hot topic among shipbuilders as they move to Just In Time (JIT) manufacturing. Bath has been able to work out arrangements with many of its sub-contractors to provide parts on a 72 hour basis. The plate manufacturers could support this if the plate required was not MILSPEC.

Another aspect of the problem is that a commercial product may be available that offers superior performance at reduced prices. Standards and Specifications reform is aimed at being smart about procurement. The barriers to making smart decisions need to be eliminated. In June of 1994, Secretary of Defense Perry called for the use of "performance standards or non government standards to define new systems and system

modifications. Military specifications are only to be used as a “last resort”, with an appropriate waiver.”<sup>10</sup>

Looking at the Affordability Crisis, the Standards and Specification program should also act to reduce the cost of providing Required Level of Capability to the Navy. By removing the barriers to less expensive alternatives, the Navy promotes competition among suppliers that should result in less expensive components.

COTS and Standards and Specification reform played a large role in the LPD-17 acquisition program. This ship was just recently awarded to the Avondale/Bath team. Most of the ship had been designed by the time Secretary Perry discussed his vision for reforms. Much effort was expended to sanitize the contract of government specifications after the fact. More of an impact will be felt if these reform measures are implemented during preliminary design. Despite its late start, COTS and Standards and Specifications will have a significant impact on the end cost of the LPD-17. Quantifying this impact will be critical for proponents who want to continue the movement away from MILSPECS. Without a way to measure the long term benefit of these programs, the process may revert to the better known MILSPEC methods. If future programs are as attentive to what they ask of the contractor, the cost of building Navy ships could be reduced.

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<sup>10</sup> Perry, W.J., (1994), Specifications and Standards - A New Way of Doing Business, SECDEF Memorandum, 29 June 1994.

## 2.23 - The Affordability Through Commonality (ATC) Program

The goal of the ATC program is to improve the process by which the Navy, designs, acquires, and provides lifetime support for ships used in national defense. By standardizing equipment and designs across the fleet, economies of scale could be generated. Reducing the number of different parts in the fleet improves the ability to maintain or replace these parts. By building standard modules, the designs would become more mature.

The increased use of commonality in naval ship design and acquisition will:

- Reduce design requirements and construction time
- Maintain reasonable procurement quantities at the equipment/subassembly levels
- Improve shipbuilding quality control
- Permit ease of maintainability and upgradability.<sup>11</sup>

The ATC program receives its funding through the National Shipbuilding Initiative established by President Clinton in 1994 to stimulate commercial shipbuilding in the United States. The approach used to achieve this goal is a combination of modularity, equipment standardization, and process simplification. The ATC office was established to develop necessary strategies, standards, designs, specifications, and procedures to lower costs of fleet ownership with commonality.

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<sup>11</sup> Cable, C. W. and Rivers, T.M. (1992). Affordability Through Commonality. ASNE DDG-51 Technical Symposium.

The current Navy order book does not support long production lines on which productivity improvements could be made. Instead of building many of the same ship, the ATC program promotes the use of common modules across ship classes. In this way, economies of scale could be achieved. Prototype modules have been developed for habitability, machinery/auxiliary systems and combat systems. Reducing the number of different parts supported throughout the Navy would allow great reductions in the cost of the maintenance system as well.

Another tenet of ATC is process simplification of production, logistics and requirements. Process simplification includes the following:<sup>12</sup>

- Standard designs for Hull, Mechanical and Electrical (HM&E) systems
- Elimination of unnecessary military specifications and standards
- Procurement of equipment in large lots to support fleet levels
- Generic build strategies at the fleet level
- Efficient standard assembly of major systems and equipment
- More production oriented distributed systems architecture
- Increased concurrent assembly and testing of equipment and systems during construction
- Fewer different types of systems to support
- Replaceable components and subassemblies to ease upgrade

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<sup>12</sup> Bosworth, M. L. and Hough, J. J. (1993). Improvements in Ship Affordability. The Society of Naval Architects and Marine Engineers Centennial Meeting.

Several other industries have promoted commonality across product lines as a way to reduce costs including the automobile industry. When Ford is set to develop its next pickup truck the product development engineers make a conscious effort to use as many successful components from existing vehicles as is practically possible. This reduces the total product development cycle while providing mature systems intact around which to build the new design. As in the car industry, the use of increased commonality in naval ship design and acquisition can lead to shorter design and construction times.

If cycle times can be reduced, the program costs and risk will also be reduced. Additionally, the use of common components allows economies of scale to be realized despite the decreasing number of ships being built. Commonality fosters improved quality control and facilitates ease of maintenance and upgrade. Examining the Affordability Crisis, ATC should contribute in several ways. First, by making ships more common, the database of products offered can be reduced. This allows the use of more mature designs that reduces the risk associated with new product development and the total acquisition cost.

By producing many of the same module, the commercial industrial base could be increased. Perhaps some of these modules could be used in commercial ships or off shore platforms. This would reduce the cost of building commercial ships that could become a competitive advantage for the shipyards. Standard propulsion packages like the LM-2500

have been successfully used fleetwide for the last twenty years. Similar gains in commonality would act to reduce the cost of Navy ships.

While ATC promotes commonality across Navy designs, the problem is that the program still uses Navy designers to develop the ATC modules. Forcing a shipbuilder to use a Level III drawing prescribed by NAVSEA removes his initiative to improve the process. Assuming that these modules could be built the same way for the same cost in any shipyard is not realistic. Real standardization must come from the shipbuilders and must be suited to their individual capabilities. They must be allowed to provide their knowledge to the process. In order for ATC to reach its full potential, the different program managers of the major ship programs need to choose standard components. Is the SC-21 program manager going to accept the same combat systems architecture as LPD-17? How much of the fleet can really be common? How difficult is the integration of an entire module into a ship design? Is ATC really worth the trouble?

The ATC program also needs to find ways to quantify the savings that increased commonality can produce. These savings come in many forms including design, construction, maintenance and upgrade costs. Without a Life Cycle Cost (LCC) estimating method, the true benefits of ATC can not be balanced against the costs. Current program managers tend to look only at the savings the program can provide to construction costs. A wider view over the life of the ship must be used in measuring the ATC benefits. Tools must be developed to provide this big picture perspective to the program managers and the Navy. *“Actual, detailed real life costs to produce a ship are*

*not known. To realize the full cost savings benefit of modularization, supportive ship architectures need to be incorporated in Navy ship designs and must be designed from the ground up.*"<sup>13</sup>

### **2.3 Commercial Shipbuilding Initiatives**

The commercial shipbuilding market has been described as a “dog fight where nobody makes any money.”<sup>14</sup> Indeed the profit margins in an industry that faces huge over capacity are low. Many countries, including Japan and Korea, have propped up their national shipbuilders to gain a dominant portion of the market. With a large order book, the market leaders have been able to upgrade their practices and implement new technology into production lines. The rest of the participants in the commercial shipbuilding world, U.S. yards in particular, have been left behind in terms of cycle times and productivity. Without proper market forces to correct for these government subsidies, the glut of excess tonnage will continue.

The National Defense Authorization Act of 1993 lay the groundwork for a comprehensive plan to ensure that U.S. shipyards could eventually compete in the international shipbuilding market. From this act comes a plan that attempts to:

- Ensure fair international competition ~

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<sup>13</sup> Bosworth, M. L. and Hough, J. J. (1993). Improvements in Ship Affordability. The Society of Naval Architects and Marine Engineers Centennial Meeting.

<sup>14</sup> Buttner, S., (1997) Interview conducted at MIT.

- Improve domestic competitiveness
- Eliminate unnecessary government regulations
- Finance ship sales through Title XI loan guarantees
- Assist International Marketing

The benefits of this legislation are starting to materialize. Some commercial work has been stimulated although the jury is still out over whether this has improved productivity in warship construction. It may be time to revisit this initiative and to redirect its efforts to more productive areas. Some suggest a return to the Construction Differential Subsidy of the seventies<sup>15</sup>. Others call for tax benefits for shipbuilders. Finally a call has gone out for increased funds for education. All of these are good ideas. Some will have a more immediate effect than others. Again the problem is quantifying the true impact of any of these programs individually or comprehensively.

## **2.31 MARITECH**

Several foreign shipyards have established themselves as market leaders in international shipbuilding. The Marine Systems Technology (MARITECH) program has been designed to promote technology transfer, process improvements, product development, and productivity and quality enhancement in US shipyards. Ishikawajima-Harima Heavy Industries (IHI) Marine Technology in particular has been tapped for its expertise as a world class shipbuilder by several U.S. yards. Focus areas include shipbuilding standards, producibility, productivity, and shipyard management.

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<sup>15</sup> O'Neil, D.A., (1997) Is Our Military Unwittingly Helping to Scuttle the US Merchant Marine?, Sea History 80, Winter 1996-1997.

MARITECH is a government cost-sharing program established by President Clinton in 1994 to assist defense department shipyards in the research and development of new designs for commercial ships. The program has generated several interesting ship designs in this country. It remains to be seen if the domestic ship owners are willing to invest in American built ships when they can buy less expensive ships overseas.

Looking at the Affordability Crisis, the MARITECH program attempts to increase U.S. Productivity using best practices from foreign yards. If the positive feedback loop that drives the costs of U.S. Ships can be properly stimulated, the commercial industrial base may see an increase in Order Book as the Cost Differential swings more in favor of US yards. The increased commercial work will lead to further improvements in productivity and eventually additional cost savings. The initial stimulation of this feedback loop is the critical component that is currently missing.

The differences between building conventional commercial ships like tankers and bulk carriers and combatants may not facilitate increased productivity across product lines. Perhaps high performance commercial ships may be the answer to improving the construction of combatants. Several designs are currently available that attempt to capture a high end container market. These designs use high performance hull forms and advanced propulsion systems. If a commercial market for these type vessels could be established, real savings on combatant ships may be realized while regaining a substantial share of the commercial market.

### 2.32 National Shipbuilding Research Program (NSRP)

The Merchant Marine Act of 1936 as amended in 1970 established the NSRP for the purpose of providing a forum for productivity and technology improvements for the U.S. shipbuilding industry. The mission of the NSRP is to “collaborate with shipbuilders in developing plans for the economic construction of ships.” Nine panels have been established to allow interaction between industry, the Navy, and academia. These panels include:

- SP-1 Facilities and Environmental Concerns
- SP-3 Surface Preparation and Coatings
- SP-4 Design/Production Integration
- SP-5 Human Resources Innovation
- SP-6 Marine Industry Standards
- SP-7 Welding
- SP-8 Industrial Engineering
- SP-9 Education

*“The NSRP is a nationally recognized model for government/industry research program.*

*It has made a significant effort to maintain the industrial base needed for national security.”*<sup>16</sup> If this is the case, then why can’t any U.S. shipbuilders produce a commercial

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<sup>16</sup> Rivers, T.M., Schiller, T.R., (1995) Naval Affordability: Right Heading, Wrong Course, Annual Meeting of the Society of Naval Architects and Marine Engineer.

ship as fast or as inexpensively as Japanese yards? The NSRP may provide the forum for discussion but it seems obvious that the time has come for action and not words. To get real improvements in productivity, revolutionary change is needed in the domestic shipbuilding industry. Years of surviving on government contracts has ended. The shipyards that cannot adapt and become more efficient need to be allowed to be driven out of business regardless of the political ramifications. Shipbuilding is an industry subject to market conditions. If the US government does not allow the market to weed out the dead weight, real productivity gains will never occur. The only true competitive advantage is the ability to innovate faster than your competitors. If US shipyards are not forced to innovate based on market forces, they will never become competitive on a world level.

The NSRP hosts a Ship Production Symposium annually. The major shipbuilders come together to discuss the industries problems and to try to find ways to solve them. Although some progress has been made, it seems the shipyards are not yet hungry enough to make radical improvements to the way they build ships. Many of the papers presented were interesting and generated discussion. They included modularity and product model development. These were the same topics presented at the symposium back in 1993! When will these ideas finally begin to catch on in the industry?

When viewed in the context of the Affordability Crisis, the NSRP acts to increase US Productivity by stimulating change in the industry and introducing best practices from

world class shipyards. The NSRP carries out an important function although the benefits are hard to quantify.

### **2.33 Mid-Term Sealift Ship Technology Development Program (MTSSTDP)**

The MTSSTDP is a program that uses the shipyards, university personnel, vendors, design consultants and the NAVSEA Shipbuilding Support Office (NAVSHPSSO). The major objectives of this program include:

- Construction Contract Cycle Reductions
- Initial Acquisition Cost Reduction
- Replacement of MILSPEC Equipment with commercially acceptable versions
- Development of Enhanced 3-D Design Tools with access to Expert Systems for Lessons Learned
- Identify and recommend change within the NAVSEA acquisition process

One significant contribution of the MTSSTDP has been the evaluation of dual use ship designs. The main objective of this effort is to stimulate commercial shipbuilding while producing valid assets that can meet the U.S. surge and follow on Sealift requirements in the future. The program attempts to produce designs for a container ship that can compete in commercial markets. This ship would also have installed National Defense Features (NDF) allowing it to be rapidly converted to a military useful ship in time of national emergency.

When viewed in the context of the Affordability Crisis, this program makes perfect sense. To meet our transportation needs, the United States has relied on commercial shipping to provide Sealift capacity in time of war. In the eighties, the government chose to purchase excess commercial ships and maintain them in a reduced state of readiness in the Ready Reserve Force (RRF). Experience during Desert Shield/Desert Storm indicates this may not be the most effective way of acquiring capability. The “mothball fleet” was much harder to activate than originally anticipated. Many ships on a five day alert status required several weeks to get underway. Foreign container and break bulk ships were chartered to make up the shortfall in RRF assets. In the next national crisis, foreign assets may not be available to pick up the slack for the RRF.

The cost of maintaining the RRF at the pier in a degraded state of readiness should be traded off against subsidizing the construction of new commercially viable container or RO/RO ships. With the proper NDF features, these ships could be immediately used in time of war. In peacetime, they could be used to deliver cargo in Jone’s Act trade or in the international markets. The Future Technology Variant (FTV) is the design proposed by the MTSSTDP. A commercial operator, Crowley, evaluated this ship and determined it to be not commercially viable when compared to a similar ship currently in operation. The subsidy to make up the difference in operating costs would be over \$2 million dollars/year.<sup>17</sup>

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<sup>17</sup> Crowley Report Assessment of FTV, March, 1997.

A better suggestion would be to start with a commercially viable high performance container ship like FASTSHIP Atlantic or BATHMAX 1500. The only subsidy required from the government may be a construction subsidy for installation of NDF items and perhaps some guaranteed military cargo for the first few years until high value markets can be stimulated. If this high speed container ship concept gains market share, the US may be able to capture the high value container market while providing a superior asset to military planners in time of war.

### **2.34 Lean Shipbuilding Initiative**

Another program that is in the very early stages of development is the Lean Ship Initiative (LSI). This program is in the formative stages at NAVSEA. It attempts to combine industry, the Navy, and academia to study the way ships are manufactured in this country and to find ways to improve the process. Womack, Jones and Roos define the basic Lean principles in their work, "The Machine That Changed the World," that examined the automotive industry. The Toyota management, design and production methods were investigated and determined to be superior to the mass production techniques used in this country. Several large domestic automotive firms including Ford and GM have chosen to make themselves more Lean as a result. Roos updates this work with the current diffusion of Lean principles into other industries.<sup>18</sup>

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<sup>18</sup> Womack and Jones, (1996), *Lean Thinking*, Simon and Schuster, New York, NY

Lean approaches have had great impact in the domestic automotive, aerospace and other complex manufacturing industries. In some cases, these industries were in grave danger of being forced out of the market in which they operate. Japanese firms could produce similar products at higher levels of quality for less money. Adapting Lean principles calls for a revolutionary change to the way a company deals with its customers, suppliers and employees. This change will result in the breaking of established paradigms. It can be a very hard transition to make. It has also become necessary in the international, inter-connected world of today.

The key Lean principles include:

- Perfect first time quality through a quest for zero defects, revealing and solving problems at their ultimate source, achieving higher quality and productivity simultaneously, teamwork, and worker empowerment
- Waste Minimization by removing all non-value added activities making the most efficient use of scarce resources (capital, people, space) just-in-time inventory, eliminating any safety nets
- Continuous improvement (reducing costs, improving quality, increasing productivity) through a dynamic process of change, simultaneous and integrated product/process development, rapid cycle time and time to market, openness and information sharing
- Flexibility in producing different mixes or greater diversity of products quickly, without sacrificing efficiency at lower volumes of production, through rapid set-up and manufacturing at small lot sizes

- Long term relationships between suppliers and primary producers (assemblers, system integrators) through collaborative risk-sharing, cost sharing and information sharing agreements built upon a sense of mutual obligation, openness and trust.<sup>19</sup>

The domestic shipbuilding industry is ripe for revolutionary change. If ever an industry was the opposite of Lean, shipbuilding in this country fits the bill. After touring five of the six major shipyards in the past year, it is my observation that none of the key precepts of a Lean organization are being used. The relationship between the government and the shipbuilders is adversarial. Because protracted disputes with the government often lead to financial duress, the prime contractor usually squeezes its sub-contractors for every last penny as well. Piles of inventory and work in progress (WIP) were the norm instead of the exception. Some of the smaller shapes produced at Bath Iron Works, for example, were stored in an open field under snow after being manufactured. Employee relationships were strained as the shipyards constantly look for ways to cut costs. The easiest way to reduce overhead is to layoff workers. This problem was observed at every shipyard visited. It will be discussed later in Chapter 5.

Lean manufacturing holds great promise for shipbuilding. Shipbuilding can be considered a cross between a craft trade and a mass production trade. The products are very complex and built in small numbers. Many of the sub-assemblies that are used to

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<sup>19</sup> Lean Sustainment Initiative - Massachusetts Institute of Technology

build ships have very similar characteristics. If we consider these sub-assemblies the products and make them as common as possible, an agile manufacturing process could be developed to produce the different components in the same way on the same machines.

Japanese shipbuilders are able to produce military and commercial ships similar to those built in the U.S. using shorter cycle times and with fewer man hours. A comparative study of US and foreign shipbuilders, outlined in Table, quantifies the differences between the foreign and domestic yards.<sup>20</sup> The product of interest is the construction of 54,000 dwt tankers.

Productivity	Japan	Korea	Germany	US
Employee-Days/Ship	45,000	99,000	65,000	100,000
Hourly Compensation (1990 US Dollars)	16.00	7.8	26.5	15.6
Total Labor Charges (\$ million)	5.76	6.17	13.78	12.48

**Table 2-2 - US vs Foreign Productivity**

As U.S. shipbuilders try to get back into the commercial ship building market, they will need to compete with the Koreans and the Japanese. The wages for US workers have dropped below the level of much of the foreign competition. The real area in which improvements need to be made is worker productivity.

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<sup>20</sup> Simmons, L.D., (1996) Assessment of Options for Enhancing Surface Ship Acquisition, Institute for Defense Analyses, Alexandria, VA.

Instead of competing directly on standard container ships and tankers, several yards have announced plans to investigate the high performance shipbuilding market. Cruise liners, high speed ferries and fast container ships are more complex than product carriers or tankers. They have more in common with the warships U.S. yards are accustomed to building. Either way, adjusting their operations to becoming more Lean can only help US yards. With a leaner industrial base that can compete internationally, the Navy may be able to realize cost savings as the processes used in U.S. yards improves.

The principles associated with Lean manufacturing have been discussed in the industry individually as improvements to the process. Many yards have used foreign technology transfer programs under NSRP during the 1980's. These yards tended to pick one or two good ideas to on which to concentrate their time and money. Bath is trying to cut its working inventory from 9-12 months down to 2 weeks. Ingalls is moving to Integrated Product Teams internally to get cross trade improvements at the design level. NASSCO is trying to choose standard component parts that can be aggregated into all of the complex units needed to build a ship. If the parts at the lowest level of manufacturing are common, economies of scale can be realized. It then becomes a process management problem to put these pieces together in an economical way. If implemented individually, these measures will have some impact but not realize their true potential.

To really make a difference in the industry, more needs to be done. The government needs to rethink the way that contracts are let. The government acquisition

strategy needs to take into account the long term needs of the shipbuilder. Long term relationship with sub-contractors needs to be cultivated which contributes to Just In Time delivery of components. The entire Lean package must be put in place. This will cause great angst in the industry. By taking a broader systems view of the industry, we can find the true leverage points on which to concentrate. It may require closing some of the privately owned yards that survive on defense work and starting with a clean sheet of paper. The reopening of the Quincy Shipyard offers a unique opportunity to view the retooling of a shipyard from the beginning. Clearly, the status quo is not satisfactory. Real change, initiated by the only real customer, the government, is required. Hard decisions need to be made. The sooner they can be implemented, the sooner the domestic shipbuilding industry can become world class again. The first step to improving the process is understanding the complexities involved. One method for identifying and dealing with complexity is a Build Strategy which will be discussed in the next section.

## ***2.4 Build Strategy Development***

New product development has been the topic of studies in many industries over the last few years from software development to the automotive industry. The technicians at Toyota, with their Lean production methods, seem to have mastered the product development process by bringing all the critical personnel together early in the project. All the difficult decisions concerning the design and production of the new product are discussed and formalized. In this way, the design does not need to go through

generation after generation of change as the development process matures.<sup>21</sup> Similarly, Japanese shipbuilders have shown that by investing critical time before the start of construction to plan and integrate all the processes involved in the design and construction of a ship, great improvements in performance can be achieved.

For U.S. shipyards to compete with the Japanese for commercial ship contracts, a thorough understanding of the product and process is required. A Build Strategy goes a long way towards identifying exactly what the product consists of and the process that will be used to manufacture it. Three critical components of any project are coordination, cooperation and communication. The Build Strategy acts as a facilitator for each of these components.

## **2.41 Description**

Any complex project requires an in depth plan of action and milestones for proper execution. Shipbuilding is no different. All shipbuilders plan how they will take the customers' requirements and coordinate their assets to satisfy them. The plan may be the result of a detailed analysis conducted by many people or it may be one experienced manager's vision of how things should be done. This plan, in shipbuilding, is defined as

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<sup>21</sup> Womack, J.P, Jones, D.T., and Roos, D., (1990), "The Machine That Changed the World," Rawson Associates, New York, NY.

the Build Strategy. *“A Build Strategy is an agreed design, engineering, material management, production and testing plan prepared before work starts, to identify and integrate all necessary processes.”*<sup>22</sup> It represents the culmination of many decisions that must be made by the company to remain competitive yet produce a quality ship.

A Build Strategy does the following things for a company:

- Applies a company’s overall shipbuilding policy to a specific contract
- Provides a process for feedback between design and production to introduce production engineering principles that can reduce ship work content and cycle time
- Determines resource and skill requirements and overall facility loading
- Identifies shortfalls in capacity in terms of facilities, manpower, and skills
- Provides baseline schedule for production planning and ordering of long lead time material
- Identifies and resolves problems before work on the contract begins
- Ensures communication, cooperation, collaboration, and consistency between the various technical and production functions

The problem with a Build Strategy is that once it is completed it becomes a static document. Once the project starts, the Build Strategy goes on the shelf as “...the

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<sup>22</sup> Lamb, T., (February 1994), Build Strategy Development, The National Shipbuilding Research Program, Carderock Division, Naval Surface Warfare Center, Bethesda, Maryland

perfect plan that never was.” All the work and decisions that went into the development of the strategy are filed away until the next ship project. This is why many shipyards know what a Build Strategy is but do not find the value added in producing a new plan for each ship.<sup>23</sup> If the Build Strategy could be made interactive where the production planners could actually revisit their decisions as the project progresses, they may get more use out of the effort. In this section the components for a Build Strategy are described. These components will be described in more detail in the Build Strategy Document found in Appendix A and then converted into structure and policies in the Ship Production Model.

## **2.42 Components**

The Build Strategy should make all assumptions and objectives about a project clear to the project management team, the workers executing the plan, and the customer. The Build Strategy represents the culmination of all the shipyard's experience, resources and capabilities. It is critical for each yard to know its strengths and weaknesses and to know when it is reaching a constraint in the system. If a constraint needs to be eliminated, it is critical to know what the next constraint may be. Proper planning can avoid many of the difficulties associated with the constraints of a yard. Equally critical is for the customer to know and understand these constraints. If a certain change order will result in a disruption of the core business or delay delivery of the ship, it is imperative that the customer know this. A lack of understanding for the true cost of change made

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<sup>23</sup> Lamb, T., (February 1994), Build Strategy Development, The National Shipbuilding Research Program, Carderock Division, Naval Surface Warfare Center, Bethesda, Maryland

late in a project has resulted in many disputes between the shipyards and the government. If the shipyards had the tools to demonstrate the true cost, many changes may have been reserved until the next ship in the series.

The components of a Build Strategy include:

- Ship Description
- Applicable Regulations
- Quality
- Contract Requirements
- Product Work Breakdown Structure
- Master Equipment List
- Design and Engineering Plan
- Material Plan
- Build Plan

All of these will be described in greater detail in the Build Strategy for a specific ship, Sealift Option, Commercial Viability (SOCV). Many of the inputs and the outputs will be used in the Ship Production Model. The Ship Production Model is a System Dynamic model of the construction process. The model makes the Build Strategy interactive and dynamic. It can be used in the initial stages to try out different hypotheses concerning staffing, schedule, infrastructure and shop loading. As the process matures it could be updated using real performance data concerning productivity and quality. It

could be used for evaluating different scenarios concerning the project. It takes many of the management decisions needed to create a Build Strategy and creates a dynamic tool.

By using a well-defined Build Strategy with an interactive model, US shipbuilders could gain insight that would have taken years of commercial work to achieve. The use of simulation could become a competitive advantage for US shipbuilders. By being able to “test drive” a project from start to finish without expending significant capital, many different courses of action could be investigated. In this way, the “best” plan for how to build a ship could be determined before one piece of steel is cut.

An interactive model requires that all assumptions and boundaries must be made explicit. The model could be used as a communication tool between the customer and the shipbuilder. Instead of hiding the true objectives from each other, an open and cooperative environment could be created.

The current state of shipbuilding in the U.S. is far from an open and cooperative environment. The U.S. Navy is the only real customer in the market. For this reason, shipbuilding contracts are fiercely competitive. The low bidder usually has difficulty producing a ship for the promised price. Contractor/customer relations suffer as the shipyard tries to recoup some of its losses. The use of a Ship Production Model could improve these relationships by making the assumptions of both sides clear. If a dispute over the cost of certain changes occurs, the model could be used as a mediation tool, avoiding costly litigation.

## ***2.5 Dynamic Project Modeling***

Dynamic models, like the Ship Production Model mentioned in the previous section, have been used for years to settle many different disputes. Several of these disputes have involved shipbuilding. The purpose of this paper is to introduce Dynamic Project Modeling in the early stages of a project as a proactive means of: production planning, hypothesis investigation and communication. Modeling can have a much larger impact on the performance of the project instead of just as a retroactive tool to assess blame.

As previously mentioned, the process of building Navy ships may be one of the most complex processes undertaken in this country. Many groups have a vested interest in Navy ship building programs. The huge amounts of money expended and the nature of the construction process contribute to this complexity. The political ramifications of a large ship contract further complicates the situation as Members of Congress try to protect the jobs of their constituents. The Navy chooses to competitively bid its contracts adding competitive dynamics to the process. Because of this complexity, some Navy programs result in huge cost over runs and experience schedule delays in delivering the product.

Even the most experienced program manager has difficulty mentally accounting for all the critical factors involved in a program at one time. People are more comfortable

dealing with ideas that are linear and easily quantified. Many factors involved in shipbuilding are dynamic in nature, meaning they change over time. Most of the factors described in the Affordability Crisis are out of the program manager's control. Many of the problems he/she must deal with are exogenous to the shipyard. The dynamic variables, like quality and productivity, associated with shipbuilding are not so easily measured. Even when they can be measured, they do not represent the current state of the system as they are constantly changing. The causal nature of product development projects has been well documented in other System Dynamics.<sup>24</sup> Managers understand and can describe feedback acting in the process. From experience they can say that changing this will have an impact on that. Assessing the strength of several causal loops or quantifying the relationship one variable has on another is not easy in the abstract. For this reason, many important decisions are made based on “gut feel.”

Systems Dynamics is a field developed in the 1960's by Professor Jay Forrester at MIT to try to quantify “gut feel.” He felt too many decisions were being made for the wrong reasons. By systematically defining all the variables in a problem using mathematical relationships, the problem can be reduced to black and white instead of shades of gray. These mathematical relationships can then be tuned based on real life data to provide a mathematical representation of the world. This representation is subject to the assumptions and boundaries used to create the model. In the next section, the

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<sup>24</sup> Ford, D. N., (August 1995), “The Dynamics of Project Management: An Investigation of the Impacts of Project Process and Coordination on Performance,” PhD Thesis. Sloan School of Management. Massachusetts Institute of Technology. Cambridge, MA.

models that deal with the shipbuilding industry will be discussed. These models have been used effectively by very few people. The time has come to use System Dynamics models to address many of the questions raised in the previous sections of this chapter.

## **2.51 History - Ingalls Case Study**

Project modeling has become one of the most popular uses of System Dynamics in the field. Professor Edward B. Roberts, an original student of Jay Forrester, pioneered this approach at the Sloan School of Management. His doctoral dissertation concerning “The Dynamics of Research and Development,” in 1962 has led to many further studies at Sloan of Project Dynamics. Professor Roberts founded the consulting firm Pugh-Roberts with another of Jay Forrester’s students, Alexander Pugh. Pugh-Roberts specializes in building complex System Dynamics models for clients in many fields. Many firms have found this method very useful to gain insight into the operations and management of their businesses. These firms include major automobile manufacturers, semi conductor companies, chemical companies, shipbuilders and a growing number of others. The System Dynamics approach allows firms to capture the causal relationships and non-linear behavior of the manufacturing processes. Several firms including, General Motors and Eastman Kodak, have internalized the process of System Dynamics modeling and consider this process a major competitive advantage. They have used models to examine their own company, the competition, and the market in which they operate.

Interestingly, the project model that has gained the most notoriety in the field of System Dynamics is the Shipbuilding Model built by Pugh-Roberts Associates in support

of a delay and disruption case by Ingalls Shipbuilding against the U.S. Navy. The claim arose as a result of significant change orders submitted by the Navy on the LHA and DD-963 contracts of the mid '70s. The hard core costs of these changes were generally agreed upon. Hard core costs consist of the material and man hours needed to accomplish a task. What was not agreed upon was the cost of delay and disruption caused by these changes at an advanced stage in the execution of the contract. It is much more difficult to quantify delay and disruption than the hard-core costs. The claim amounted to nearly \$500 million dollars, a sum that could have put Ingalls out of business if not recouped.

Both sides agreed some delay and disruption was justified. The difficult part came in determining what would have happened if the Navy did not order changes. Many other factors were discussed as possible contributions to the cost over run. Material delays and a labor problem resulted in some loss of time. Problems with the new designs led to significant internally generated change. The role of the model in this case was to *"...develop and use a methodology that would (a) correctly quantify Navy responsible delay and disruption costs in the design, procurement, planning, and production stages of the programs, and (b) demonstrate the cause and effect relation of the costs to the items cited in the 'hard-core' segment of the claim."*<sup>25</sup> It was able to simulate the performance of the project to a high degree of accuracy. It was then able to determine how much of the disruption was caused by Navy generated change orders.

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<sup>25</sup> Cooper, K. G., Dec 1980, "Naval Ship Production: A Claim Settled and a Framework Built.", *Interfaces*, Vol. 10, No. 6.

This model has been credited with significantly contributing to the settlement of the case in favor of Ingalls for \$447 million dollars.

Ingalls has since used this model to improve the management of their shipbuilding processes. The extent to which Ingalls still uses this model will be discussed in the Chapter 3 on shipyard visits. That the management was able to take ownership of the model and use it for purposes other than litigation is very intriguing. A visit to Ingalls was conducted to investigate the effectiveness of this model and to determine to what extent it was being used. Perhaps System Dynamics modeling is a valuable tool that the Navy has thus far overlooked in the management of complex projects. Ken Cooper, a senior manager at Pugh Roberts infers at the end of his discussion of the model that perhaps a similar model could be used to the positive benefit of both parties.<sup>26</sup> If both the Navy and the contractor had a systems view of the construction process, perhaps the inevitable conflicts that arise during the management of any large complex construction program could be more readily resolved at a local level.

This model is very large in comparison with other project models. It depicts the entire shipyard in considerable detail, modeling the processes of several shipbuilding programs. The sectors modeled include:

- Acquisition and Utilization of Manpower
- Scheduling and Performance of Work

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<sup>26</sup> IBID

- Rework Generation and Scheduling
- Managerial decisions at different levels within the organization

The model captures the feedback and non-linear way the different sectors interact. Each shipbuilding program contains multiple phases of design and construction. These phases include system and detail design, material procurement, production planning and control, and four stages of ship construction. In each phase, manpower utilization of several trades, the accomplishment of work, the creation of rework, productivity, and technical complexity are all represented.

The phases interact with each other. Detailed design has a great impact on the accomplishment of work phase. If detailed design drawings are incorrect, work done in the production phase will be done wrong as a result. This creates a management dilemma. Do we fix the problem with rework, scrap the old and remake this particular component, or do we go forward with errors intact? The schedules of all phases are interdependent. Difficulties or delays experienced in upstream activities can result in future delays or require out of sequence work in later phases. If material ordered for the On Unit construction phase does not arrive on time, the entire module may be delayed until a replacement can be found. The entire build strategy may be disrupted as a result.

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The model was constructed over a period of two years by a small working group including shipyard personnel and consultants from Pugh Roberts. Interviews were

conducted with managers from all phases of shipbuilding as well as experts in government contracts and litigation. A massive amount of data was collected and analyzed to assemble a preliminary mathematical model of a single phase of construction. The model was reviewed by the project team and structural changes were made. Extensive statistical testing of the model was used to tune the model. In the end, the model was able to replicate most of the major performance measures associated with the project to a high degree accuracy.

Several key structures were developed in this model that have become standard for project models in general. These include:

- Rework
- Labor Allocation
- Overtime
- Interaction of Phases

All of these will be incorporated into the Ship Production Model presented in Chapter 4.

The participation by Ingalls management created a tool that has great potential. It combines the experience of years of shipbuilding in an interactive and dynamic model. After the settlement of the claim, Ingalls was able to use the model to its benefit. How it is currently used at Ingalls is the topic of the next section.

## **2.52 Ingalls Internal Use of the Shipbuilding Model**

The Shipbuilding Model was the product of years of work investigating, analyzing and modeling the way Ingalls build ships in its yard. Many of the critical items identified for incorporation in a Build Strategy are present in the model. Ingalls makes use of simulation to improve their internal management practices. The Shipbuilding Model developed by Pugh Roberts is still in use today. It is maintained and calibrated by Pugh-Roberts consultants. It is used as a strategic tool by upper level management although it has had an impact to much lower levels in the yard. Specific uses include:

- Bid/Risk Analysis
- Competitor Bid Analysis
- Program Management Assistance
- Change Management
- Benchmarking/Evaluation of Best Practices
- Evaluation of Process Changes/Transitions
- Dispute Avoidance/Resolution
- Program Manager Development

During the visit to Ingalls, a meeting was conducted with the simulation group who work directly with the model. They were asked to provide specific cases in which the model was used. The group pointed to:

- Evaluation of infrastructure constraints: Would a new Butt Welder improve the throughput? What is the real choke point for the manufacturing phase of

construction? The model indicated that the Butt Welder was no the constraining factor.

- Manning Assessment. How many people does it really take to build a DDG? Historically the level was set at 1100 people. The Strategic Model indicated the ship could be built with 850 with no loss in schedule. The production people claimed there was no way this could be done. Finally senior management cut production personnel to 850. The model turned out to be correct. The same work could be done with 250 fewer people in the same amount of time. The current manning levels on the DDG-51 being built at Ingalls is 850 people.
- Assess the impact of 3-D CAD on the shipbuilding process. The Navy has been pushing for 3-D CAD. The shipbuilder wanted to know what the impact this large investment in software would have on the bottom line cost of building a ship. The modeling group was able to quantify a savings of only \$200K/ship as a result of the new CAD package
- Shipyard Loading: What is the impact of emergent new work? The USS Gonzalez runs aground in the Caribbean and needs to be dry docked and repaired. Will this work package disrupt our core business? The determination was made that work would negatively impact core business. A bid on the emerging work was not submitted.
- Hiring Firing Policy Formulation: What does it really cost to cut experienced labor? Model determined that it is more economical to maintain hull and

mechanical people doing less complex barge work than laying them off. Even though Ingalls may take a loss on the barge work, they avoid much larger penalties trying to find qualified labor when needed. This is perhaps the most valuable insight provided by the model. Every shipyard visited mentioned the problem of finding good workers when needed. Every shipyard also mentioned cutting their work force when the order book is low. Only Ingalls was able to quantify the cost of rehiring these people or training replacements. This topic will be visited in the analysis section of this paper as a case study.

The simulation group indicated they had some problems with the model. The group felt the model was not agile enough for everyday use. Much of the large structure used in the original litigation case is still present in the model. They were frustrated that it was a legacy system with assumptions which are not documented. Because of this the simulation group is not able to examine the shipyard on the level that can be used on a weekly or monthly basis. They would like to be able to disaggregate to the level where the true impact can be realized. The strategic model is not as flexible a tool as they would like.

The simulation group would like to make use of a Graphical User Interface (GUI) that is available for more current System Dynamics modeling packages. The present model, built in DYNAMO, displays inputs and outputs but not model structure and equations. The group would like to be able to examine the model equations. They would

also like to be able to modify structure as needed to provide a wider range of simulation topics.

Ingalls has a great advantage due to its previous use of Dynamic Modeling. The management team understands the systems approach. They know that carrying additional people until the next peak in production pays off in the end. After twenty years, it is clear that the model used at Ingalls needs an overhaul. Current System Dynamics software packages like ITHINK or VENSIM provide a user friendly interface to investigate the model equations and make local changes. Pugh-Roberts could go a long way to helping the Navy define what is needed to help all of the domestic shipyards take advantage of this type of simulation.

## **2.53 Halter Marine**

Another example of the use of System Dynamics for shipbuilding is the Halter Marine Case. The model used in this case was also built by Pugh-Roberts. A graduate student at Sloan School of Business, Kim Reichelt, examined this case for her thesis. Because most of the models used by Pugh-Roberts are proprietary, examining the equations and structure they use is impossible. This case study provides an interesting look at commercial shipbuilding. Many of the conflicts experienced in Naval ship construction also occur in commercial shipbuilding. This case also provides a model that uses much of the Pugh-Roberts project model structure.

The dispute in this case was between a shipbuilder, Halter Marine, and a ship owner, Leon Hess. The conflict concerned who was responsible for cost overruns on a ship construction project in the mid 80's. It was standard practice in the commercial shipbuilding industry to continue with a job whether or not disputes could be immediately settled. Negotiations to sort out the claims of each party were then held after the project was completed. In this way the customer could put his new vessel to work generating income and the shipbuilder could get on with other work. In the Halter case, the customer refused to settle the dispute on terms amenable to both sides. Again, the shipyard would be forced to go out of business unless it could win a reasonable settlement.

### *Competitive Dynamics*

Several key insights into the dynamics of shipbuilding come out of this work. First, the bidding process is critical to the entire system. The competitive dynamics of the industry drive shipbuilders to come up with the low bid to win a project. This leaves the customer in an awkward position. If the bids are too low, should the customer hold the yard to a bid he can not deliver? Low bids usually mean the shipbuilder will need to make money other ways like growth on the contract. If the bid is too low it may also mean that the contractor really does not understand the complexity of the project. A fair bidding price is critical to the success of a project. All aspects of the project need to be accounted for. Choosing a builder solely based on bid price is foolhardy at best. If there is not a thorough review of the proposals for completeness, the program manager is sure to experience a degraded relationship with the builder as nickel and dime dynamics come into play as the contract progresses. The Navy could learn much from this case. During

the 1980's, the Navy chose to award contracts based almost exclusively on the lowest bid price. This has led to a very poor working relationship between the government and industry as many programs have experienced cost over runs and schedule delays.

The natural reaction is to blame the other party for the cost over run or schedule slippage. The government blames the contractor for trying to squeeze more money out of the contract. The contractor accuses the government of changing the contract at an advanced date. Both sides may be justified in their argument. Determining who is responsible for what part of the costs fairly is critical to a good working relationship. If projects remain constrained by impossible cost or schedule goals, both sides are setting themselves up for a difficult time. Hopefully, the acquisition reform measures that are being investigated will look hard at the way contracts are awarded. A well thought out shipbuilding plan with margin for error seems much more attractive than a bid generated to be the lowest no matter what the real cost to the government and the contractor.

### *Overhead*

Shipbuilding is characterized by a relatively small number of large projects. Fluctuating orders require frequent changes in yard capacity. *“The ability to tailor shipyard overhead to shipyard order book requires special attention. Without this ability, overhead becomes exorbitant.”*<sup>27</sup> Halter Marine was structured to deal with this volatility. The company was easily able to cut back its work force by closing mobile

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<sup>27</sup> Reichelt, K. S. (June 1990) Halter Marine: A Case Study in the Dangers of Litigation. Master's Thesis. Sloan School of Management. Massachusetts Institute of Technology. Cambridge, MA.

yards and to expand its work force by double shifting or working overtime. Through double shifting alone it was able to increase productivity in the short term by around 33%.<sup>28</sup> Every shipyard visited discussed the problem of cutting overhead, both labor and facilities in lean times. This is a key strategic decision that will be discussed in depth later.

### *Labor*

Because of the desire to cut overhead, labor relationships between the shipbuilders and their workforce can be strained. Halter Marine is one of relatively few non-union shipyards in the country. In its 25 years of operations, Halter never had a work stoppage, strike or even a major labor confrontation. Halter Marine employees were well rewarded for top performance through the Halter Incentive Program (HIP). It provided cash awards to employees for achieving quality and productivity improvements. Absenteeism at Halter was less than 2%.

### *Management*

Most of the management at Halter was promoted from within the company. Internal promotion acted to increase motivation for Halter employees who saw a career path to which they could aspire. It also gave them added respect for the management as they came up through the ranks.

### *Product*

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<sup>28</sup> IBID

The characteristics of the product can play a large part in the performance of the project. Vessels that are of a standard design with few new components tend to do better than innovative designs. The innovative designs the Navy has used in the past may not be affordable in the future. If a completely new design is determined to be required, decision makers must be willing to pay the price for the product and process changes that come with new designs. The Cat Tug, built by Halter can be considered an innovative design. It consists of a large barge driven by a catamaran tug. Halter had difficulty producing what the client actually wanted due to design problems.

The Naval Architecture firm constantly made changes to the contract to improve the design. The increased scope was to be negotiated after the delivery of the first ship. This is typical of the way the Navy does business as well. Change orders are used to improve the design after the contract has been awarded. This change throws off the planning sequence developed in the Build Strategy. It may lead to delays in construction, out of sequence work or a disruption of the core business. Change orders should be kept to a minimum once the detailed design is set. If there is concern for the quality of the design, the changes need to be made up front and not after material is being manufactured.

### *Scope*

The shipyard likes increase in scope as it provides more work for their order book. The Navy has used change orders and increased scope to a varying degree on different projects. It is critical that this increased scope be properly documented, priced and negotiated as it occurs to get the real cost of change at certain times in the contract. If

change is allowed to be introduced too far into the construction process, the core work could be interrupted. Even removing items from the project can prove detrimental as management may have already expended a significant portion of the money allotted to that item prior to cancellation.

### *Hiring/Firing*

More engineers were needed to deal with the owner directed changes on the Cat Tug project. Overtime was increased and new people were hired. This action led to exactly the opposite result intended. Instead of an increase in productivity due to more people, the productivity dropped significantly. Two dynamics are at work here. First, the Rookie vs. Veteran dynamic occurred. New people are hired to fill a gap in the project. They take some time to get up to speed before they can make a positive contribution. Experienced people need to take the time to indoctrinate the new people. The total effect is to decrease the overall productivity of the group. This puts the project even farther behind schedule.

Overtime can work to improve productivity in the short term. It is used throughout the industry to try to limit the amount of fluctuations in the work force. Top managers know they will pay a price in productivity if they need to hire new people. To avoid this, in times of increased workload, management offers overtime to the experienced workers. Too much overtime leads to fatigue in the workplace. This can cause additional errors to be made, safety hazards and poor employee morale. All of these factors combine to further degrade the performance of the project.

While changes were ongoing in the engineering and detailed design phase, construction at Halter began. Large numbers of revisions were being made to the original plans by engineering making the planning and execution of construction difficult. Overtime was already being required in construction, adding to productivity problems. Additionally, some major equipment was late in its delivery. The delays in this project started to affect the performance of the yard in general.

Changes continued without Halter being reimbursed. The company began to sink its own money into the project. The engineering problems got worse further delaying the project. Almost all of the initial drawing had been issued. Problems with the original drawings required revisions. All of these problems exacerbated construction problems leading to out of sequence work and the use of overtime. New workers were hired to pick up the slack, further eroding productivity. As both budget and schedule pressures arose, morale began to suffer.

Due to enormous losses on the project the HIP was suspended further eroding the morale of the workforce at the Chickasaw yard. Chickasaw soon had the highest absenteeism and turnover in the company which further degraded productivity. Cash flow problems soon led to Halter losing its position as a market leader. Threats of bankruptcy continued to erode worker morale.

Halter was forced to sell to Trinity Marine for \$23 million, one quarter of the value of the company only 3 years before. The decline in Halter's value can be attributed to a general decline in the oil industry at this time. The problems with the Cat Tug project accelerated Halter's fall as an industry leader by weakening its strategic position in the market and keeping it from developing new business.

The problems with the Cat Tug program were inevitably felt by management as well. Under pressure to increase worker output to get the program back on schedule, managers tend to tinker with their policies. In order for these new policies to have the desired effect, a period of adjustment is required. This worse before better dynamic further erodes the efficiency of the workforce. If the project reaches such low performance levels that the management needs to be replaced, additional problems are the result. When new management is acquired, labor productivity will suffer until the new manager is up to speed.<sup>29</sup>

## Summary

Disruption costs are difficult to quantify by either the contractor or the customer. Neither party is likely to anticipate all of the disruption to the original plan that the change will cause. In general, the hard core costs of the change are quantifiable based on some previous job of similar complexity. Difficulty arises in trying to put the change in the context of the entire project. In some cases the change will be hardly noticed at the

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<sup>29</sup> Hammon, C, Graham, D.R., (1980), "Disruption Costs in Navy Shipbuilding Programs," CNS 1149-Vol. 1/October 1980, Center for Naval Analyses, Alexandria, VA.

shop level. In other cases, a ripple effect will occur which impacts every process downstream. The work required to accomplish the change in scope may be done at lower productivity rates than normal work. The disruption caused by this change of scope requires significantly more work than normally would be anticipated.

The causes of delay and disruption or indirect impacts have been well documented. They include out of sequence work resulting in lower productivity. Lower productivity means more hours are required to get the same amount of work done. To compensate for this loss of productivity or poor schedule performance, management may elect to increase overtime for the current workforce or hire new workers. In the short term, more overtime will increase the productivity per day. In the long run however, the use of excess overtime will lead to fatigue, further degrading productivity.<sup>30</sup> Hiring new people will initially lead to a drop in productivity as the more experienced people are forced to train the rookies. Adding more people often leads to having your best people spending their time training new people. This can further dilute the team's productivity.<sup>31</sup> This dynamic is well understood in other industries. Brooke's Law, from software development, states that adding labor to a late project makes it even later.<sup>32</sup>

All of these effects may be resolved if the scope and impact of the changes to the original plan are realized. With the proper tools, a cost vs. schedule analysis could be

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<sup>30</sup> Homer, J.B., (1985), "Worker Burnout: A Dynamic Model with Implications for Prevention and Control," System Dynamics Review, Vol.1, Summer 1985

<sup>31</sup> Abdel-Hamid and Madnick, (1988)

<sup>32</sup> Sterman, J.D., (1992), "System Dynamics Modeling for Project Management," unpublished working paper, Systems Dynamics Group. Sloan School of Management. Massachusetts Institute of Technology.

conducted. If schedule adjustment is feasible, delaying the project long enough to work through the out of sequence work would be the logical choice. If the client demands adherence to the original schedule, he must be willing to pay for the disruption. Program managers have not had the tools to do such comparisons in the past. Perhaps with Systems Dynamics modeling, they can determine the real costs of change and make decisions accordingly.

## **2.54 Other Systems Dynamics Models**

Several System Dynamics models are in use or being developed that could provide insight to shipbuilding managers. The most mature of these is offered by Pugh Roberts. They continue to advise Ingalls Shipbuilding using the Strategic Model previously discussed and the Program Management Modeling System (PMMS) which has been used for a variety of industries. *"PMMS can reflect differences in technology, productivity, labor utilization, management, government regulations, business culture, and political environments that exist from one industry or one country to another."*<sup>33</sup> Other shipbuilding clients have included Newport News Shipbuilding and Electric Boat. No formal reports or documents have been generated concerning the impact of Systems Thinking on these yards. It would be in the best interest of the Navy to pursue tools like System Dynamics to aid in understanding the shipbuilding process.

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<sup>33</sup> Management Simulation Group of PA Consulting Group Informational Pamphlet

One software package under development that could be used to study the shipbuilding industry is ShipBuild. This model is being built by Decision Dynamics, a modeling group out of Washington D.C. ShipBuild has been proposed as a planning, analysis and cost estimating tool for simulating the dynamics of shipbuilding activity. The current version is more similar to a static project planner like Microsoft Project or Computer Associates' Super Project. The next version will include many of the dynamic features previously discussed. Using ShipBuild, a project could be developed using traditional CPM or PERT methods. The dynamic portion of the model could then be utilized for analysis of different scenarios involving policy changes, design changes, or schedule vs. cost scenarios as the project progresses. One sector of this model is provided in the Users Manual. It is shown in Figure 2-9. It contains variables like Rework, Productivity, Work Force and the stocks and flows of a typical System Dynamics model.



established for the blocks as well. For example, Block I cannot be started until Work Package I and II are completed.

Different types of tasks using labor pools can also be identified. The schedule for the ship can be defined or automatically calculated based on the labor productivity and the amount of work that needs to be accomplished. Finally any special equipment needed to construct the ship is input. Once the Ship package is identified, the user can create a shipyard to build the ship.

In the Shipyard Sub-model, the resources available for construction are defined for the yard of interest. The Facilities section allows you to create a facility map and provide capabilities for defining management policies, work stations, and associated equipment. Typical shipbuilding facilities are provided in a Layout Library. These include items found in every shipyard like:

- Blast and Paint
- Plate Storage
- Surface Prep Area
- Plate Burning
- Plate Shaping
- Sub Assembly Area
- Machine Shop
- Pipe Shop
- Insulation Shop

- Electrical Shop
- Block Assembly Area
- Construction Ways

The capacity of each of these facilities areas can be input defining the constraints in the system.

The Management function allows the user to select and define management policies that will be applied to the study during simulation. In the current version, only a few management functions can be examined. These include policies for management response to schedule pressure caused by changes or delays as well as productivity loss from overmanning. In future versions of ShipBuild, rising schedule pressure will trigger a variety of management actions including hiring additional labor, assigning overtime, or a combination. If too much labor is assigned to the job, the net productivity eventually will decrease as interference between workers starts to occur.

These management policy structures and others are still in the developmental stage. Once they are fully operational and tested, ShipBuild will could be a valuable link between the static production planners and a fully dynamic model. The output from ShipBuild can come in several forms. Traditional Gantt Charts of the program can be displayed. All of the important variables can be viewed over time. Management policies can be manipulated to evaluate the effect of each policy on schedule and cost. *“ShipBuild gives the model user an unprecedented capability to develop and test*

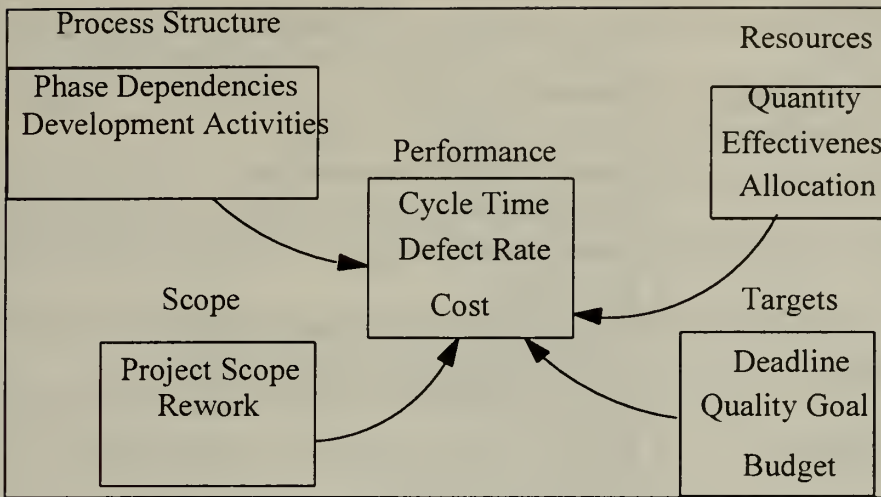
*alternative “what if” scenarios for the purpose of improving both the productivity of ship designs and the efficiency of shipyards.”<sup>34</sup>*

ShipBuild shows great promise for providing a commercial package to shipbuilders to try their own modeling and simulation. The software package is not yet available. Because of this fact, I chose to build my own models that could demonstrate the dynamic behavior of interest.

David Ford, in his dissertation, “The Dynamics of Project Management,” develops another System Dynamics model which can be used to simulate product development. His model combines many of the structures from previous work at the Sloan School of Management with new structure he built as a result of his observations of the computer industry. Project performance can be measured in time, quality, and cost. The model consists of a set of inter-related development phases and a set of management features. Each phase represents a specific stage of the product development process. The later phases depend on the products of the earlier stages. The structures and characteristics found in this model are shown in the Figure 2-10 below.

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<sup>34</sup> ShipBuild Phase II Users Guide (1996) - Dynamic Simulation Model of Shipbuilding Construction Delays.



**Figure 2-10 - Ford Major Sectors**

Ford concludes that adding feedback, delays and non-linear relationships to traditional project models results in a better picture of the real world. “Static features and impacts of projects have been extensively researched and applied to project management practice. In contrast, project managers do not effectively understand or utilize the dynamic features of development project structures. These features combine to cause projects to behave in complex ways which are difficult to understand, predict and manage.”<sup>35</sup>

The Product Development Project Model simulates a project that can have multiple development stages. This is a feature that has been observed in shipbuilding. The key structures in this model are listed below in with the model references if they exist. All of the references can be found in the bibliography.

<sup>35</sup> Ford, D. N., (August 1995), The Dynamics of Project Management: An Investigation of the Impacts of Project Process and Coordination on Performance. PhD Thesis. Sloan School of Management. Massachusetts Institute of Technology. Cambridge, MA.

Model Structure	References
Close Loop Flow of tasks	Cooper (1980), Richardson and Pugh (1981)
Internal/External Work Constraints	Homer et al. (1993)
Recycling of Flawed Work (Rework)	Cooper (1980), Kim (1988)
Interaction of Phases	Cooper (1980), Reichelt (1990)
Gross Labor Sector	Abdel Hamid (1984), Richardson and Pugh (1981)
Labor Allocation	Abdel Hamid (1984)
Workweek	Kim (1988)
Fatigue Effects	Homer (1985), Abdel Hamid (1984)
Learning curve/Productivity	Abdel Hamid and Madnick (1991)
Schedule Pressure	Roberts (1974)
Perceived vs Actual Progress	Roberts (1974), Richardson and Pugh (1981)
Schedule Estimates	Abdel Hamid (1984)
Project Quality	Fiddeman, Oliva, and Aranda (1993)
Project Cost	Abdel Hamid and Madnick (1991)

Table 2-3 - Ford Model Structures

Ford's model requires reconfiguration to depict the shipbuilding process. It was originally used to examine computer product development. This model has proven very valuable as an example of how to tie everything together for a multiphase project model. The complexity of the model and the fact that it is written in Dynamo made refining it for my purposes too difficult.

None of the models listed above were suitable for the level of analysis of this paper. The simulation done in this paper is used for proof of concept and to demonstrate the potential of the tools. To tune a System Dynamics model to real situations requires much more specific data and calibration.<sup>36</sup> For this reason, a simpler model, the Ship Production Model is created. This model is built using VENSIM developed by Ventanna

<sup>36</sup> Lyneis, J.M., (1980), Corporate Planning and Policy Design., Cambridge, MA, The MIT Press.

Corp. Several of the project structures used are found in the Molecules, a supplemental package to VENSIM provided by Professor Jim Hines of the Sloan School of Management. This model is simpler to understand and recreate than the models previously mentioned. It provides the novice System Dynamics practitioner with a useful tool to test policies and hypotheses related to building ships. This model will be discussed in greater detail in Chapter 4.

## **2.55 Potential**

Simulation in many different forms is becoming increasingly accepted as a standard engineering and management tool. The primary purpose of simulation is to reduce technical and commercial risk. Simulation helps designers and managers better understand the consequences of their actions in advance of the eventual performance of the project under consideration. The Navy, to this point, has chosen to ignore System Dynamics. ShipBuild has been mentioned in some circles as a cost estimating tool. System Dynamics has been used effectively by several commercial yards as a way to demonstrate the dynamic nature of ship building and to simulate the process. It has been used by Ingalls to manage complex ship design and production efforts by determining the future effect of actions on the project. It can provide the valuable insights that a knowledgeable customer, namely the Navy, needs to make good choices as well. Several scenarios can be simulated to determine the best course of action, thus reducing the risk on the project. System Dynamics provides a way to quantify a good managers “gut feel”. Using historical data, actual behavior can be simulated with a well

constructed model. Once the model operates like the real world, projections can be made as to the future performance of the program within the limits of the model.

The emerging emphasis on the use of integrated teams in new procurements accentuates the need for a common framework. Using this framework team members can agree in advance on a course of action based on the expected outcome of these actions. If all team members are privy to the assumptions and structure in the model, this tool could be used proactively to settle disputes, should they arise, thus avoiding costly and damaging litigation. System Dynamics modeling is well suited to provide this capability. It forces the users to think about the system in which they are working. It provides insights into dynamics that are hard to quantify without the use of a model or years of experience. Thus far, System Dynamics has been a closely held, proprietary management tool. Hopefully, simulation will play a more extensive role in communicating among stakeholders in the shipbuilding process to the benefit of all.

## Chapter 3 - Shipyard Visits

In order to learn how ships are built and what factors affect productivity, a series of shipyard visits was conducted. In this chapter the different yards will be discussed.

The yards visited include:

- Ingalls Shipbuilding, Pascagoula, MI
- Bath Iron Works, Bath, Maine
- NASSCO, San Diego, CA
- Avondale Shipbuilding, New Orleans, LA.

A specific shipyard will be chosen to build SOCV. With the constraints of the shipyard, a Build Strategy will be developed geared for that yard. The timing of source selection is critical to developing an effective design. An effective design enables the performance the customer desires yet reflects the “design for producibility” features that increase shipyard productivity. Source selection depends on many attributes of the shipyard. The yard must have:

- Technical competency to build this type of ship
- Capacity in the yard to absorb the work
- An adequate pool of skilled labor
- Installed machinery and facilities to fabricate, erect and launch the ship

In the past, source selection has relied heavily on the bid price. Over the last twenty years, this trend has led to major conflicts between the government and the contractor as described in Chapter 2. Some shipyards would underbid the competition to win the

contract despite the real costs to build the ship. Once the contract was awarded, the costs would escalate to a point where the shipyard could make some money. A broader view of the capabilities of each yard, combined with bid price and Total Ownership Costs (TOC) should be used in the future to make better decisions.

The purpose of the shipyard visits was to determine:

- Which yards have the capability to build the SOCV
- How ships are built in this country
- What factors affect program performance in the major US shipyards
- What are the constraints to production
- What are the factors that effect quality and productivity

These yards represent a significant portion of the Navy warship building in this country. Ingalls and Bath build surface combatants. NASSCO builds auxiliaries and Sealift Ships. Avondale builds amphibious ships, oil tankers and Sealift Ships. Newport News builds aircraft carriers, submarines, Sealift Ships.

Over the last few years many domestic shipyards have pursued commercial contracts to supplement their Navy work. NASSCO has delivered the most recent commercial work with open top container ships for Matson Lines in 1992. Avondale Shipyards has been working to develop a small commercial niche for product tankers. Newport News and Avondale may have a distinct competitive advantage over the other yards in this country with their ability to attract commercial contracts. Many people in

the industry think both yards will lose money on these efforts. The true payoff to increasing the amount of work flowing through the yard is not easily quantifiable. Increased throughput allows productivity gains and maintain a steady workforce. The benefits of these effects will not be realized on one ship. The benefits of increased throughput will show up in the overall health of the company.

Cost effective commercial shipbuilding may be the future for US Shipyards. The amount of Navy work currently being contracted is not enough to keep all of the large shipyards active, let alone profitable.<sup>37</sup> Without throughput, shipbuilding processes do not evolve. Without continued improvement, US shipyards will fall further behind the foreign competition. Without another source of work similar to the core competency of building warships, several of the large yards will be forced to close.

Areas of interest examined at each shipyard include:

- History
- Financial Status
- Current Navy and Commercial work
- Future Strategic Plan
- Shipyard Layout - Key Factors include:

- Land Area
- Pier Space
- Crane Capacity
- Blast and Paint Facilities

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<sup>37</sup> Marine Agility Group, (June 1996), 21st Century Agile Shipbuilding Strategies- Infrastructure and Business Process Opportunities

Transfer Equipment  
Capital for renovations

- Human Resource Management
- Production Planning

Build Strategy  
Constraints to Production

- Material Procurement and Handling
- Phases of Construction
- Performance
- Use of Simulation

Interesting topics specific to each shipyard are also investigated. The differences between yards and the perceived advantages and disadvantages of each are discussed. A specific comparison is made between Bath and Ingalls on the DDG-51 contract. The reasons why Ingalls consistently outperforms Bath in cycle time and cost are investigated later in Chapter 5.

### ***3.1 - Ingalls Shipbuilding, Pascagoula, Mississippi***

Areas of specific interest

- Use of System Dynamics Modeling
- Level of Outfitting
- Quality
- Ability to outperform Bath on DDG-51

- Capacity

### 3.11 History

Ingalls started building ships in 1938 with the first all welded ship. They have made considerable process improvements including modular construction on the FFG-7 guided missile frigates and DD-963 destroyer classes. Ingalls was involved with a large litigation claim against the Navy over delay and disruption on DD-963 and LHA-1 amphibious transport ship programs. This claim stimulated the use of System Dynamics at Ingalls as discussed in Chapter 2. It also launched System Dynamics as a major methodology in project management litigation. Ingalls has improved the process it uses to build ships as a result of this model. The yard has demonstrated outstanding performance on the CG-47 guided missile cruiser and DDG-51 guided missile destroyer contracts.<sup>38</sup> Since 1975 Ingalls has delivered a combination of 72 new destroyers, cruisers and amphibious assault ships to the US Navy.<sup>39</sup>

### 3.12 Financial Status

Ingalls is currently a subsidiary of Litton Industries, one of the world's leading suppliers of defense electronics and information systems. It has shown steady profits despite reduction in the number of ships currently being built by the US Navy. Ingalls continues to look for additional international combatant work with two new surface ship

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<sup>38</sup> Simmons, L.D., (1996) "Assessment of Options for Enhancing Surface Ship Acquisition," IDA Paper P-3172, Institute for Defense Analyses, Alexandria, Virginia.

<sup>39</sup> Litton Industries Inc., (1996), Building Toward the Future, 1996 Annual Report.

designs, a 1300 ton corvette and a 3000 ton frigate. The financial performance of Ingalls is shown in Table 3-4.<sup>40</sup>

<b>Ingalls Financials (\$ millions)</b>	1996	1995	1994
Marine Engineering and Production Revenues	\$1294.6	\$1396.1	\$1484.1
Marine Engineering and Production Operating Profit	\$142.5	\$131.6	141.1
Profit Margin	11.01%	9.43%	9.51%
Revenues/Employee (\$000)	117	101.2	101

**Table 3-4 - Ingalls Financials**

Margins at Ingalls have been steady. A measure of effectiveness of the shipyard is revenues generated per employee. Over the last few years this number has been increasing at Ingalls indicating higher levels of productivity. With the current procurement rate for Navy ships, Ingalls will have a major shortfall in revenues after the delivery of the last LHD amphibious transport ship. They need to stimulate some new work in order to maintain current manning levels. The future of Ingalls depends on its ability to continue to win contracts from the US Navy. Without this base of work on which to build, the yard will be in serious financial trouble. The recent award of LPD-17, an amphibious assault ship, to the Bath/Avondale consortium has left Ingalls in a delicate position. The yard is currently working at around 30% capacity. Further erosion of the work backlog will force Ingalls to take drastic action.

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<sup>40</sup> Litton Industries Inc., (1996), Building Toward the Future, 1996 Annual Report.

### 3.13 Current Navy and Commercial Work

Ship Type	No.	Size	Customer	Value (Millions)	Delivery
DDG-51	8	6600 lt	US Navy	2,696.4	12/01
LHD-1	3	28,200 lt	US Navy	2,287.7	7/00

**Table 3-5 - Ingalls Order Book**

#### Navy Work

- The core work at Ingalls is the DDG-51 program. Management counts on maintaining at least 1.5 ships per year through 2010 when the last ship will be delivered in the class. Management at Ingalls would like to get more of this work. With recent developments at Bath on the LPD-17 and Arsenal ship programs additional DDG-51 work may shift to Ingalls.
- Ingalls has recently delivered the last ship in the CG-47 program.
- The Wasp Class LHD-1 represent the largest Amphibious ships in the fleet. Ingalls has built five of these helicopter carriers and has orders for three more.
- Foreign military sales include the construction of the SA'AR-5 class corvette for Israel. This class represents a quantum jump in stealthiness of small combatant ships. Ingalls also offers a 3000 ton frigate for sale overseas.
- Ingalls also does significant repair on CG-47, DD-963, DDG-993 amounting to \$74.2 million in FY 96
- Arsenal Ship - Selected for Phase II. They are teamed with Lockheed Martin and Newport News Shipbuilding on this innovative design. The small number of ships projected for this class is less attractive to Ingalls than the LPD-17 contract.

- LPD-17 - Lost bid to Bath/Avondale team. Decision under appeal. Teamed with NASSCO and Newport News Shipbuilding. The Build Plan for this ship seemed to be flawed. The front end of the ship was to be built at Ingalls taking advantage of its combat systems integration skills. The aft portion of the ship was to be built at Newport News. The two pieces of the ship were to be joined during erection at Ingalls. Transporting half of a 25,000 ton ship 1500 miles for final erection and having both pieces fit together is quite a challenge. The problems associated with this plan may have contributed to the contract being awarded to another team.

### Commercial Work

- Ingalls has not built any commercial ships since 1973-1974 when it built 4 container ships for American President Lines. They are currently building some small barges to keep hull and mechanical labor employed until the next spike in production. Ingalls is not actively seeking commercial work as they believe their niche is in high performance combatant ships.

### 3.14 Future Strategic Plan

Ingalls future is dedicated to building complex combatant ships for the US Navy and for foreign export. The specific ships Ingalls seems to be concentrating on include:

- Ingalls would like to be the sole yard for all DDG-51 contracts - they feel they can build these ships more efficiently than BIW.
- Arsenal Ship - Teamed with Lockheed Martin on innovative ship program.

- SC-21 - The Navy's future surface combatant. Still in concept stage. Ingalls would like to be a major part of this contract as this is the only surface combatant program on the horizon
- Trying to stimulate foreign military sales of SA'AR class or slightly larger frigate design.
- May be able to compete for CVX if the Navy chooses to pursue a smaller, conventionally powered variant.
- May need to revisit position on commercial work. Ingalls is an ideal candidate to build SOCV Project. The Build Strategy for SOCV is oriented for Ingalls.

### **3.15 Shipyard Layout**

- Land Area - 569.2 Acres of developed land, 788.8 total acres
- Pier Space -2.2 miles of dock space
- Crane Capacity - Portal Cranes - 15 heavy lift cranes operate off a fixed track system in bay areas and on the wharves. Capacity ranges from 39-300 tons. Lift reach 50-200 ft
- Blast and Paint Facilities - Large building used for surface preparation and painting of larger blocks. Additional blast and paint area not in use. The capability exists to blast and paint large blocks. There was little evidence of extensive use of this facility and it certainly was not a choke point.

- Transfer Equipment - Launch/Translation Dry-dock - Capacity - 30,000 long tons. Limitations: 50 tons per foot loading, 175 ft width, 850 ft length. Meets SOCV constraints. Provides great flexibility to waterfront area.
- Capital for renovations - Ingalls feels it has more than enough capacity and technology to produce ships for the Navy. They seem to be holding off on large capital investments until the current order book stabilizes.

Figure 3-11 depicts the layout at Ingalls.

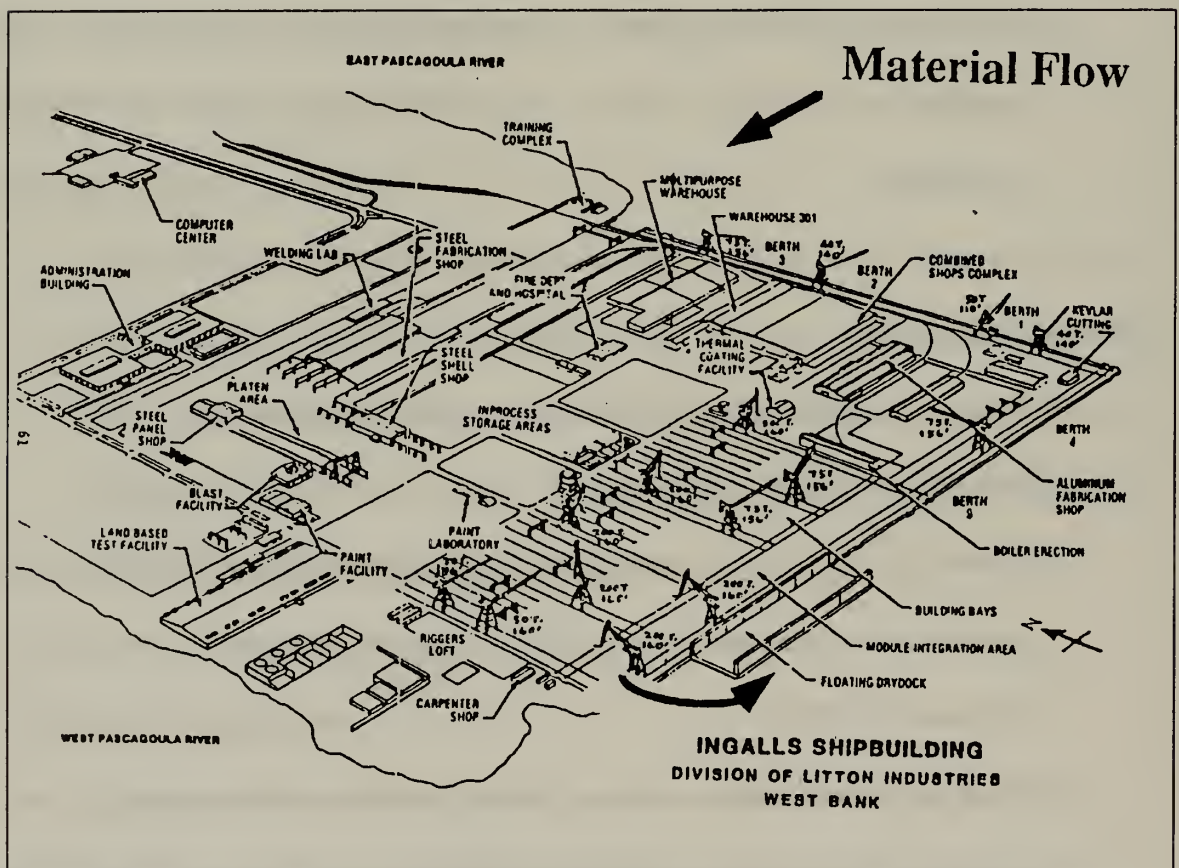


Figure 3-11 - Ingalls Shipyard Layout

### 3.16 Human Resource Management

The management at Ingalls realizes that maintaining a stable, experienced workforce is the key to remaining competitive. They are frustrated with the current order book they maintain. In order for them to make significant improvements in cycle time and productivity, there needs to be sufficient work to keep the yard gainfully employed. Some characteristics of Human Resources Management at Ingalls include:

- Understand the value of maintaining experienced labor
- Working to instill team concept between trades
- Utilizing Covey training (7 Habits of Effective People) to increase productivity
- Workforce - 11,000 workers down from a max of 25,000 in the late seventies
- 10 years average experience
- Mostly union workers
- Mississippi is a “Right to Work” state, meaning the workers do not have to join union. This gives management some leverage during labor negotiations.
- Working in Integrated Product Teams (IPT). The IPT manages its own budget. In this way the people who have the most control are the ones who have the most understanding of the situation.
- Use multi-functional teams of cross trained personnel. Brings designers, CAD operators, material procurement and construction people together. Breaks down institutional barriers between departments.

### **3.17 Production Planning**

Ingalls has used Production Planning as a competitive advantage on the CG-47 class and the DDG-51. The yard is big enough to absorb much more work than they have on the order books. As will be discussed later, Ingalls has the tools to determine the most efficient values for key the parameters for building a ship in terms of cycle time and manpower utilization.

#### **Constraints:**

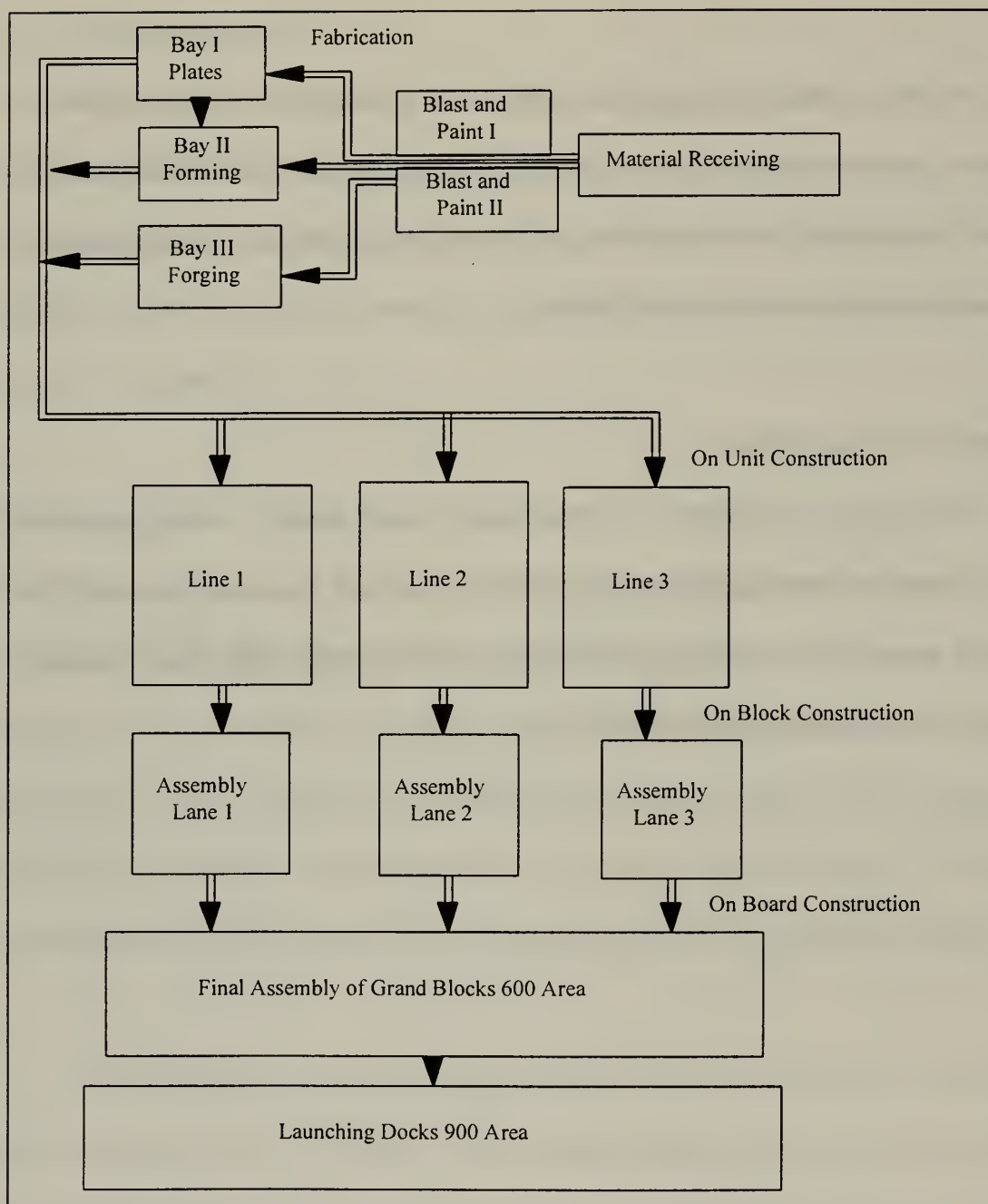
The only constraint to the shipbuilding process at Ingalls with its current order book is man power. The throughput is around 3.5 blocks per week. Production planners estimate they could increase throughput to 11.5 blocks per week without any major investments in new infrastructure. Ingalls is keenly aware of the cost of ramping up production too quickly. In the 1970's they expanded to 25,000 workers. The loss of productivity from trying to train all of these new people greatly impacted performance.

The first place a constraint would be felt is in the fabrication area. More burn tables would need to be purchased to meet a higher demand than 11.5 blocks per week. The other option would be to purchase more of the shapes used in the early stages through out-sourcing. All of the yards visited attempt to produce as much of the ship internally to maximize man hours for their labor force. The Japanese are able to out-source much of the low margin work on smaller subassemblies. US yards do not have the sub contractor relationships to allow them to achieve this symbiosis without a major change in the way they do business.

A block at Ingalls is larger than other yards. These Grand Blocks consist of a number of sub-assemblies. They can weigh as much as 250 tons. The flexibility provided by the land level translator and heavy lift capability is a great strategic advantage for Ingalls in Production Planning.

### **3.18 Phases of Construction**

Observations were made of the construction process during a walking tour of the yard. A time line depicting the way Ingalls builds ships will be compared to how Bath builds the same ship, the DDG-51, at the end of this chapter. The flow of material through the yard is represented in Figure 3-12.



**Figure 3-12 - Ingalls Material Flow**

Table 3-6 shows the breakdown by phase of standard man-hours for a typical DDG-51 construction cycle at Ingalls. It also shows the percentage of units of work broken down by phase of construction.

Work and Cost Categories	% of Total Work	Percent of Std Man-hours
Shop Fabrication & Mfg	21.9%	13.6%
Pre Outfitting Installations	11.6%	17.7%
Outfitting	23.1%	27.4%
Testing	5.1%	4.2%
Change (ECP)	28.5%	2.4%
Rework	3.3%	1.3%
Backcharge (Material Prob)	2.1%	.1%
Construction Services (Ovhd)	4.4%	33.3%

**Table 3-6 - Ingalls Work Percentages at Each Phase<sup>41</sup>**

Change represents the amount of Engineering Change Proposals (ECP) the customer submits to the contractor once the project has started. The amount of change the Navy imposes on the shipyard is too high. Once the Production Planning and Detailed Design phases are completed, changes on that particular ship must stop if we are to realize any effects of learning. Every time a change is made, it causes deviation from what has already been done. This acts to limit the productivity gains that can be realized. Although the total man hours associated with change is small, the disruption of base work can lead to significant additional charges.

The overhead rate is interesting. Typical submarine construction overhead has been quoted as at least equal to, and more likely higher than, the direct costs. The percentage advertised at Ingalls is considerably less even though Ingalls is only utilizing 30% of its capacity.

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<sup>41</sup> Philo, D. (1997) Personal Communication

## **Detailed Design**

The Ingalls design facility is very impressive. 3-D Computer Aided Drafting (CAD) is being used extensively. Although the transition to 3-D CAD has been painful, true producibility, quality and productivity improvements may be possible using a 3-D product model correctly. Ingalls is using Dimension III, a Computervision product. It has invested over \$2 billion to achieve 3-D product modeling. Specific observations concerning design include:

- 200 designers - making the transition to design build teams
- Ingalls uses line people, industrial engineers on same team as CAD operators to make sure the design is producible.
- Use of 3-D CAD for most of DDG Flight IIA
- 3-D CAD can be used to find interferences and determine proper sequencing of work
- 3-D CAD also allows Ingalls to bring the operators into the design site to get feedback on arrangements at a very early stage. This may reduce the amount of change the Navy demands on these ships.

## **Material Procurement and Handling**

Material control is able to receive up to 50,000 items /month

- Most material comes by truck
- Not much evidence of piece parts laying around the yard. Could be for lack of work. Ingalls personnel report they maintain an average of 6-8 weeks

inventory. They understand that there are internal customers in the shipyard.

These customers must be ready to receive parts before they are shipped.

- Clear areas where pieces are manufactured
- Clear plate line. Plenty of room to cut and bend initial plate
- Moving to 3-D CAD that can be linked to Computer Aided Manufacturing (CAM).

### **On Unit Construction**

On Unit outfitting is done at several shops around the yard. It takes place between weeks 28-72 for a typical DDG-51 contract. At Ingalls, On Unit represents 22.5% of all outfitting. This seemed like a low number. Perhaps the size and weather at Ingalls allow them to be more efficient than other yards in the On Block and On Board phases. On Unit assembly takes place in several specialized shops with controlled environments. Although this stage is thought to be the place with the highest outfitting productivity, Ingalls chooses to do a larger percentage in later stages. This dynamic will be examined in greater detail in Chapter 5.

### **On Block Construction**

On Block Construction is conducted in the 600 area of the yard. The structural steel components and the smaller subsystems come together in this area. The amount of outfitting done here represents 41.9% of the total. This area is out in the weather. The

blocks are extensively jigged to allow access to the different yard workers. The blocks are moved along the assembly line with overhead cranes. Specific observations:

- This area seemed congested and not environment controlled.
- Rain, heat must affect productivity and quality
- Access to services must be run via long wires or welding leads
- Level of pre-outfitting low.
- No final blast and paint prior to erection observed. This is the same as state of the art Japanese yards. The difference is that the Japanese do not have rust problems during On Block outfitting. Extensive rust could be observed at this stage which requires surface prep or rework. Touch up work or rework was being done on third shift to reduce the amount of disruption with base work.

### **On Board Construction**

Ingalls leaves a larger portion to On Board Outfitting than other yards. This part represents 34.3% of the outfitting that is done after the launch of the ship. This is the least productive of the outfitting stages.<sup>42</sup> The limited access to compartments and interference among trades makes On Board construction very inefficient. Specific observations include:

- Much of outfitting left to On Board phase
- May lead to coordination problems. Much of painting and insulation work is done on third shift
- More difficult environment in which to work than PO-2 at Bath

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<sup>42</sup> Wilkins, J.R., Kraine, G.L., and Thompson, D.H., (Aug 1993) Evaluating the Producibility of Ship Design Alternatives, Journal of Ship Production, Vol 9, No 3, pp188-201.

- Flexibility of launching methods may lead to inefficient practices.

The percentages of work done at each stage of construction are shown in Table 3-7

% of Unit Starts						
		Shop	Pre-O/F	Outfitting	Test	Change
Phase 1A	12 weeks	5.5%				
Phase 1B	12 weeks	18.2%				
Phase 2	12 weeks	21.8%	23.8%			2.3%
Phase 3	12 weeks	13.8%	32.4%	1.6%		4.1%
Phase 4	12 weeks	11.6%	31.9%	6.3%	1.1%	7.0%
Phase 5	12 Weeks	9.8%	11.9%	12.3%		7.9%
610 w/s	12 weeks	10.9%		21.2%	1.7%	10.8%
620 w/s	12 weeks	5.3%		21.1%	3.1%	9.2%
910 w/s	10 weeks	2.1%		15.3%	6.6%	13.1%
920 w/s	10 weeks	0.9%		8.5%	21.1%	11.2%
930 w/s	11 weeks	0.1%		13.6%	33.4%	10.3%
940 w/s	12 weeks			4.8%	19.2%	11.3%
950 w/s	11 weeks			0.9%	13.3%	12.8%

**Table 3-7 - Ingalls Phases and Work Start Percentages**

### 3.19 Performance

Ingalls' performance has been good for the past several years. On the CG-47 project several ships were also under budget.

- Poor schedule and cost performance on DD-963 and LHA programs led to \$500 million delay and disruption claim.
- Ingalls gave money back to Navy on CG-47 program due to process improvements.
- Ingalls has consistently out performed competition on DDG-51 program in terms of cost.

### 3.110 Use of Simulation

Ingalls was the only yard that was internally using Systems Dynamics modeling to examine their production processes. It was clear from the beginning that the senior level management understands that a systems perspective is important. The model they use will be discussed in greater detail in the next section. The uses for the model include:

- Bid Risk Assessment - the simulation group was able to manipulate the Ingalls Shipbuilding model to examine the LPD-17 work package. They were able to change work package variables in the model to simulate the work needed for a larger, less complex amphibious ship. They were also able to change the shipyard strategic variables to simulate the competitions bid based on historical data and the open literature. This allowed Ingalls to produce a competitive bid, and assess cost and schedule risk.
- Analyze the impact of alternative management initiatives striving for better program performance with lower costs, improved customer relations and improved labor relations.
- Analyze cross-program and cross functional impacts
- Forecast the time and cost at completion of on-going programs with much greater accuracy than traditional approach. This forecast can be updated based on new information concerning change to the scope of the contract or the schedule as a result of rework or customer directed Engineering Change Proposals (ECP).

- Facilities Loading and Planning - The simulation group was able to evaluate if USS Gonzalez work package would effect core DDG-51 assembly. Obviously if the yard is only working at 30% capacity, the constraints are labor and management. Key concerns for strategic planners include:
  - \* How long does it take to hire people and get up to speed?
  - \* Will we see an initial drop in productivity?
  - \* Will this drop in productivity effect the core work in the yard?
- Ingalls is able to project how long it takes for an improvement process like JIT to take effect. Worse before better dynamics will inevitably take place. The model used to demonstrate this critical behavior.
- Change Order Negotiation, Dispute Resolution - Model used to quantify change order impacts. This is done reactively, after the fact. It seems more sensible to use proactively to give a true value to the decision makers requesting the change.
- The model could be used to test suggestions on how to improve the process. This is the method the Navy should use for planning change. It captures the true impact of change to a contract and not just the direct charges. This value may not be exact but it is a better representation of the real costs that just man hours and material.
- Cost-Schedule tradeoffs can be done although the Navy has never asked for them. Only upper level management at Ingalls seem interested in this modeling. They

definitely feel there is need for use of models in resolution of these type of disagreements.

- Build Strategy - Used to look at loading of different trades and infra-structure to find optimum levels based on current order book.
- Strategic Planning - used to load yard so as not to affect core business. Would like to model all ships, only have capital for DDG-51 program

### **3.111 Summary**

My overall impression of Ingalls is the management is frustrated with the Navy acquisition process. They feel they can produce the ships the Navy desires cheaper and faster than the competition. A systems view of the shipbuilding process is evident from the “Welcome Aboard” message from the CEO to the assembly process where producibility ideas can be found. This systems perspective may have contributed to their performance improvements since the DD-963 contract. Ingalls is a large shipyard which is under utilized. It has valuable resources that are not being put to work. Ingalls is the perfect candidate to build high performance commercial ships.

For these reasons, the SOCV program office has chosen Ingalls Shipbuilding to produce this ship based on the projected order book, general characteristics of the yard, and reasonable bid price. Initial estimates place the cost for SOCV around \$250 million dollars. Ingalls has built many innovative combatant ships for the Navy. The SOCV design fits within the constraints of the yard without a large retooling investment. This

high performance hull requires the skills of a proven shipyard. Ingalls, operating at 30% capacity, can easily gear up to absorb this work in the yard without disruption to their core DDG-51 work

### **3.2 Bath Iron Works, Bath Maine**

#### Areas of Specific Interest

- Material Handling and Procurement
- Level of Outfitting
- Constraints to Construction
- Competition with Ingalls

#### **3.21 History**

Bath Iron Works (BIW) was founded in Bath, Maine in 1884. It has delivered over 400 ships since then to the world's fleets. BIW has been the lead designer and builder of half of the non-nuclear surface ships procured by the US Navy since World War II. BIW currently designs and builds the DDG-51 class destroyers. They are direct competitors with Ingalls shipbuilding. BIW utilizes modular construction techniques combined with extensive pre-outfitting of construction blocks.

BIW was purchased for \$292 million by General Dynamics on 15 September 1995. General Dynamics management initiated a program requiring its major businesses to be market leaders and have "critical mass." This is defined as "*...the appropriate size to retain key capabilities and ensure economies of scale.*"<sup>43</sup> In Shipbuilding and Repair this critical mass now consists of 2 of the 6 largest shipbuilders in the country, BIW and Electric Boat of Groton, CT. The impact of having two large shipbuilders owned by the

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<sup>43</sup> General Dynamics Form 10-Q, (August 1996)

same company remains to be seen. Economies of scale in terms of material purchases, software development, and heavy machinery purchases will be more readily realized with two large construction bases. A common information system, 3-D CAD package, and material vendors are being discussed.

### 3.22 Financial Status

The financial data for BIW are combined with Electric Boats's contribution to General Dynamics revenues and earnings. The numbers for General Dynamics are provided in Table 3-8.

<b>General Dynamics Financials (\$ millions)</b>	1996	1995	1994
Marine Engineering and Production Revenues	\$ 2,452	\$1,884	1,733
Marine Engineering and Production Operating Profit	\$218	\$194	\$196
Profit Margin	8.9%	10.3%	11.3

**Table 3-8 - General Dynamics Financial Status**

Net sales and operating earnings increased during 1996 primarily due to the acquisition of Bath Iron Works. The margins are similar to the rest of the industry, steady but not staggering. General Dynamics has made a concerted effort to capture enough of the shipbuilding market to ensure they can be competitive.

### 3.23 Current Navy and Commercial Work

The Order Book at BIW currently consists of the ships in Table 3-9.

Ship Type	No.	Size	Customer	Value (Millions)	Delivery
DDG-51	11	6600 lt	US Navy	3,276.7	08/02
LPD-17	1	25,000 lt	US Navy	500	

**Table 3-4 - Bath Order Book**

Navy Work

The bulk of the work is made up of the DDG-51 contract. Additional work includes:

- Phase II Arsenal Ship, teamed with Raytheon. BIW has been granted \$15 million to continue efforts to create Arsenal ship concept designs.
- Bath/Avondale/Hughes Aircraft Team won the LPD-17 contract on 17 December 1996. Total value of current contract for the first ship is \$641 million. The award provides options for two additional ships bringing the total value of the contract to \$1.5 billion. Bath will provide combat systems expertise for the first two and build the third ship of class.

#### Commercial Work

- Teamed with Kvaerner Masa on BATHMAX Project. Looking to bring higher speed cargo ships to the US. Products range from 500-3000 TEU container ships, Large Ferries, and Cruise Ships.
- Bath has decided to concentrate on the high performance end of the commercial spectrum in terms of complexity in the products it offers.  
*“Competing against the Japanese and Koreans in the cut throat tanker business where nobody is making money is not where we want to be.”<sup>44</sup>*

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<sup>44</sup> Suehrstedt, Eric, (1997), Personal Communication

- BIW is not pursuing commercial work as aggressively as in the past.

Sufficient Navy order book for next few years

### 3.24 Future Strategic Plan

The future looks bright for BIW. They seem to have taken advantage of some of the government funded productivity programs like MARITECH to improve their internal management practices. The new General Dynamics management team seems intent on bringing Bath into the 21st century with large investments in new infrastructure.

- Actively seeking SC-21, Surface Combatant for the 21st century design.
- \$300 million dollar facilities upgrade including land level translator. This will allow much more flexibility in the erection sequence of the different ships.
- Expanding into the river South of the finger pier
- Upgrading blast and paint - long considered choke point of material flow in yard
- Trying to reduce use of indirect labor to reduce overhead costs. This is a Lean concept. Japanese shipbuilders can produce the same ships for 2/3 the man hours of a US yard. Improvements in worker skills will allow US yards to make similar improvements.
- Treating structural steel and outfitting on same billing system allowing better tracking of progress.

- Having mechanics do their own QA prior to passing on down the line with check sheets. Another Lean concept. This technique can ensure point of origin discovery of errors.
- Total revision of initial MRP process for fabrication facility at the Hardings plant. Could increase productivity and quality significantly if implemented correctly.
- Bath may have trouble integrating new work into it's core DDG-51 work. Studies need to be done to ensure core work not disrupted by LPD-17.

### **3.25 Shipyard Layout**

- Land Area - 56 Acres between Bath and Portland facilities
- Pier Space - 4 Berths
- Crane Capacity - Biggest crane is 330 ton on erection ways. Additional 220 ton crane supplements large crane. Limited to 220 ton erection blocks. Use overhead cranes in pre-outfit areas to move WIP. The layout is so congested, cannot move with a fork truck. Using overhead cranes disrupts work in other areas as the blocks travel overhead.
- Blast and Paint Facilities - Facility needs to be upgraded. Constrains the construction process.
- Transfer Equipment - Use overhead cranes and heavy LO/LO trucks to move blocks around the yard. All smaller pieces fabricated at Hardings plant come to the waterfront by truck.

- Capital for renovations - General Dynamics seems to have made the decision to upgrade facilities at BIW. \$300 million in improvements are underway. Further renovations will need to be done to accommodate the LPD-17 project.
- Number of shipbuilding ways - 2 in use, 1 in reserve

Figure 3-13 shows the layout of BIW.

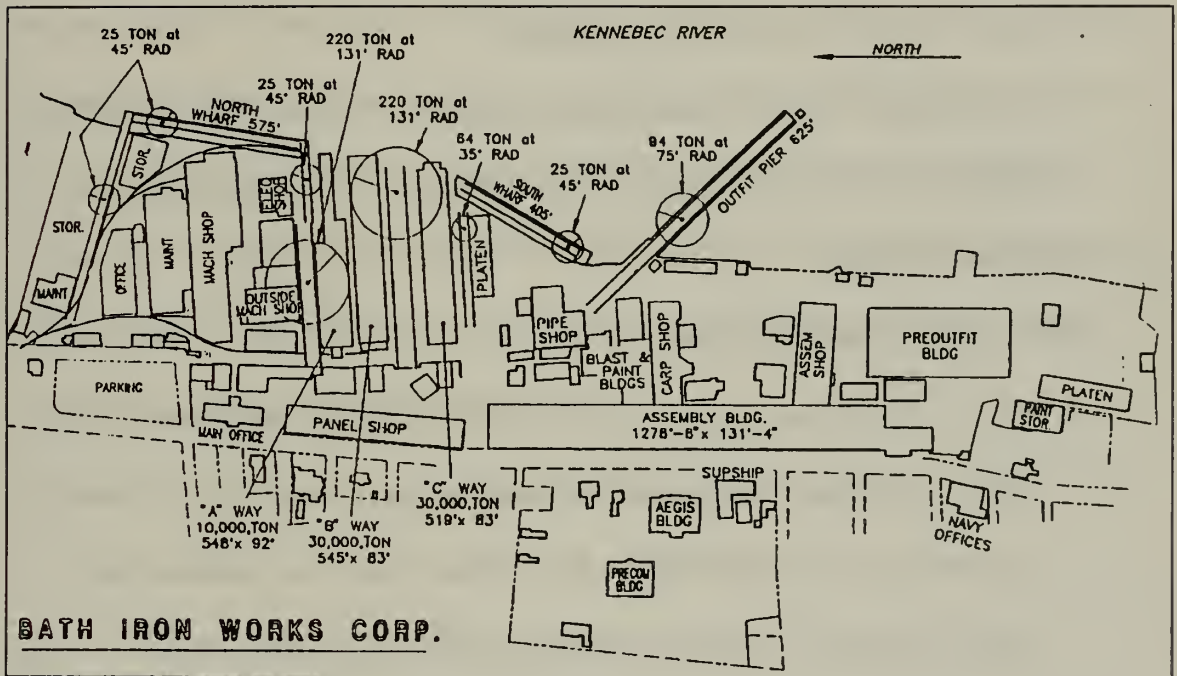


Figure 3-13 - Bath Yard Layout

### 3.26 Human Resource Management

- Size of Workforce - 7500-8000 people
- Have a hiring freeze clause in current contract with unions. This tends to reduce the volatility of the workforce. Although this restrains management from cutting overhead quickly in the short term, it may help productivity and quality in the long term as the average experience per worker increases.

- Working to cross train workforce to do more than one trade. This will reduce the number of hands required on each product over its life time. By cross training the workers, more value can be added to the pieces per worker than in the past. This is similar to innovations Japanese workers. No cleanup personnel are assigned in Japanese yards. The welders clean up after themselves when the work is completed.
- Attempting to organize workforce into Integrated Product Teams to facilitate feedback of producibility ideas from the production line to the design site.

### **3.27 Production Planning**

#### **Build Strategy and Constraints**

- The constraint many people at Bath point to is Blast and Paint capacity. At BIW, all material receives an initial surface preparation and priming. After the blocks are well established in the On Block Stage, they receive a final Blast and Paint. This limits the amount of blocks to around 2/week.
- In order to ease this constraint, BIW is investing in additional Blast and Paint facilities. None of the World Class shipyards examined in a recent technology survey conduct a final blast and paint as an entire unit. The cycle times are short enough that the initial surface preparation sufficiently protects the ship during the production process.<sup>45</sup>
- Cycle time improvement has been discussed for several years. It will require a large investment in information systems, improved material handling, better

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<sup>45</sup> Storch, R.L., Clark, J., and Lamb, T. (1995) Technology Survey of US Shipyards - 1994, presented at the Ship Production Symposium, Seattle Washington, January 25-27, 1995.

inventory controls and a faster erection sequence. Perhaps with the use of weld through primers and better material handling in the early stages, BIW could eliminate the second Blast and Paint sequence altogether.

### **3.28 Phases of Construction**

The phases of construction at BIW are limited by the Yard Layout. Expanding the yard is difficult because of environmental concerns in the state of Maine. BIW began as a yard that built wooden boats. It has evolved into a yard that builds some of the most complex ships on earth. There is a definite need for more efficient flow of material through the yard. With new contracts on the order books, the opportunity may have arrived to make a real difference in material flow and sequencing of erection. Figure 3-14 shows the material flow through BIW.

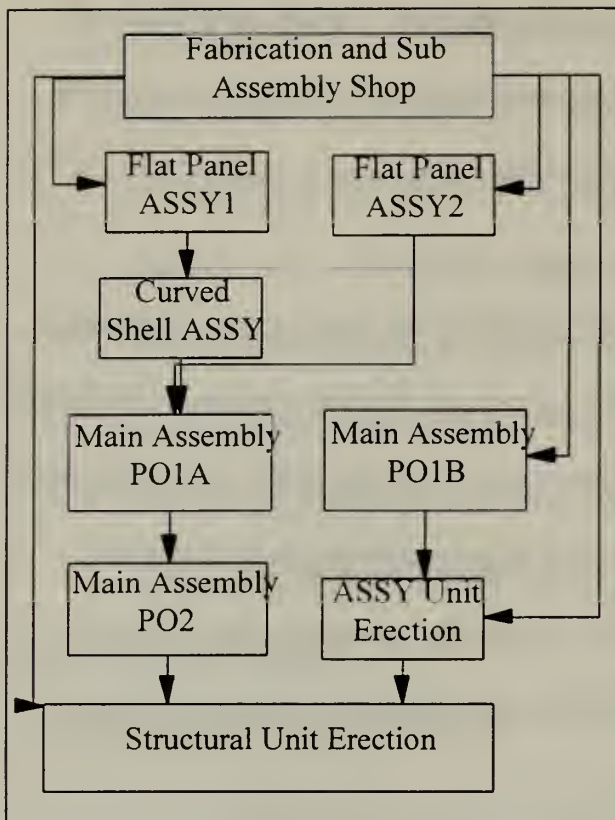


Figure 3-14BIW Work Block Assembly Flow

### Detailed Design

- Bath has been incorporating line people and industrial engineers on same team as CAD operators to make sure good production issues are established early in the process.
- They use 3-D CAD for most of DDG Flight IIA using Computer Vision software. Bath has made the commitment to 3-D CAD to have a good information interface with the Navy.
- CATEA - This capability is a function of the merger with General Dynamics. The software package can be used to find interferences and determine proper sequencing of work during the Detailed Design phase. Navy operators, the

real customer, can actually take a tour around the space to determine their preferences early in the construction process. Change in the early stages is inexpensive. If plans need to be changed to accommodate the preferences of ship's force later in the sequence, the cost of change increases exponentially.

## **Material Procurement and Handling**

Bath is moving to a "pull" system along the lines of JIT with 2 weeks inventory. They currently manufacture the parts for an entire unit to completion. Some parts in the unit are not incorporated into the ship for 6-8 months. By this time, the Work In Progress (WIP) may need additional surface prep. The parts are stored in many different warehouses. Some WIP is stored in the weather for as long as 9 months. The local manager of this process is very interested in trying to quantify some of the costs and benefits of Just In Time (JIT) to his operation. Right now he has a gut feel that smaller inventory buffers will be more difficult to manage. He feels that eventually the JIT concept will save money for the entire shipyard but these savings will not be seen at his level. The big picture is harder to see when your job is becoming more difficult. Even though the manager knows JIT is the right thing to do, implementation will be difficult. Things will get worse before they get better. By removing the buffers in the system and enforcing higher quality standards, the process will eventually become more efficient.

Specific Observations include:

- Most material comes by truck
- Going to JIT for shapes (72 hours from vendors). Reducing the number of vendors used. Shapes will come pre-kitted for one days worth of work.
- BIW's primary supplier, Bethlehem Steel is going out of business. This may force Bath to build more of its own shapes. This may take the constraints from Blast and Paint and move it to the burning tables.
- BIW cannot get its plate vendor to go to JIT due to MILSPEC DH-36. The vendor will not break up specialized steel into smaller batches. They also will only deliver plates in one load during the summer. This forces Bath to store plates in the weather all year long and pay the inventory costs. BIW would like to be able to standardize plates for LPD contract and DDG contract. This should be an action item for the producibility and ATC programs. Can the Navy accommodate BIW with a more widely made but of same quality steel that could be used for both contracts?
- BIW is moving to an automatic marking machine using Opti-Nest which determines what is needed for the next two weeks and finds the best way to cut the plate. The program goes through many possible configurations and picks the most efficient. This is different from traditional hand scribed plate. In the past, plates were marked by hand to reduce the amount of scrap produced. Opti-Nest will probably be much faster than hand marking but will result in increased remnants and possible wastage.

Management of wastage will be very important. This could be another interesting study for producibility people.

- Current material tracking system (SMIS) aggregates to level of pieces (100/product), product(1-2/unit), unit (72/DDG-51 hull) maximum 200 tons each, hull breakdown.
- There are material constraints due to heavy machinery and yard layout. Management uses flow limits to keep the process from backing up at the constraints. More study will need to be done to determine what happens when constraints are removed. Understanding choke points is critical for cycle time reductions. This is a topic for analysis in Chapter 5.
- Bath must get its manufacturing and material handling processes under control. There is much evidence of piece parts laying around the Hardings yard in piles waiting to be transported to the waterfront
- Bath builds an entire unit of work at the same time. If the waterfront is not ready for this unit, it is stored at Hardings until needed. Minimizing Work In Progress (WIP) is a critical part of the Just In Time (JIT) philosophy. The Navy should not encourage such practices with payment for work accomplished. Payments should be standardized to even out the cash flow of the contractor.
- The material remains in storage at Hardings for as long as 9 months waiting to be called by the waterfront. The process of finding the completed parts after 9 months of storage can be difficult.

- The JIT initiatives currently being put into place at BIW should help streamline the manufacturing process.
- Current plans call for the waterfront to “pull” what they need from Hardings on a daily basis. Hardings will also go to pull system internally. More emphasis is being placed on the early stages of construction. If this stage is well thought out and managed, improvements in the subsequent stages can occur as well. If the initial manufactured pieces are of low quality or inventories cannot support the work on the waterfront, the entire process will be disrupted.
- The JIT transition will be difficult for BIW. It will experience growing pains as machines and personnel that are operating at a less than optimal pace are identified. If the managers can overcome these growing pains, the JIT process will be healthy for BIW.

### **On Unit Construction**

Bath uses its covered shops to produce much more than Ingalls in the On Unit phase. Because of their constraints for waterfront space, BIW pre-outfits to a larger percentage. This acts to increase the quality and productivity of the outfitting work. Moving larger units around the yard is a constraint. Whenever a unit is moved, work on the rest of the modules comes to a halt. Specific observations include:

- Most lifts are made with overhead cranes.

- Bath produces as much of what will go into the ship as possible. Its union agreements call for as many man hours as possible go to Bath workers.
- Working in controlled environment indoors clearly yields higher quality products.

### **On Block Construction**

- At Bath, much of this stage is out of the weather. This increases both the quality and the productivity of the workforce.
- Bath pre-outfits in this phase to the maximum extent possible before conducting a final blast and paint.
- The final Blast and Paint is the bottleneck in the entire construction process but yields higher quality products.

### **On Board Construction**

- BIW is limited to two final construction/launch areas or ways. They have a third area but are hesitant to invest the money to make it active. These facilities are in constant use. A critical factor for Bath is to reduce the amount of time the ship spends on the erection ways.
- Bath has been able to reduce this time to a little over 9 months. As their order book becomes more diversified in the next few years, coordination of the erection sequence will be very important.

- By the time the ship is launched, the ship is between 72-74% complete. The remaining work consists of pulling cables and fitting the sonar dome. This will be discussed in greater detail at the end of this chapter.
- Bath has been pursuing accuracy control to the point where they can cut neat the erection blocks. The objective of cut neat is to allow the blocks to come together with little or no modifications. This goal is ambitious. Current accuracy control at BIW does not support this goal.
- The addition of a land translator will make this stage more flexible. Bath is currently limited to two erection sites. With a land translator they could put more of their waterfront space to work simultaneously.

### **3.29 Performance**

BIW has maintained adequate performance on its contracts with the Navy. It produces quality products on time and for the most part under budget. Bath has not been able to produce ships as inexpensively as Ingalls do to their internal process constraints. The Navy seems to value the quality BIW is able to build into the ships as is evident by its continued support of Bath with new DDG orders.

### **3.210 Use of Simulation**

The managers at BIW all expressed interest in the use of simulation as a way to improve their planning processes. In particular they would like to see:

- JIT - What is the improvement to the bottom line of moving to a JIT inventory process. The current manager at Hardings would like to be able to justify expenditures to upper management. Right now he feels that he is making the right decision although he wonders about the magnitude of investment in capital and man hours required to produce the desired result. Simulation would reinforce the positive aspects of JIT.
- Bath would like to be able to run several scenarios to determine which is more cost effective for the initial manufacturing processes, build parts at BIW or subcontract them out.
- Choke Point Analysis - Determining the true constraints of the yard is critical to reducing cycle times. Being able to pinpoint the place in the yard that requires an infra-structure upgrade has great value.
- Finally, being able to quantify the requirement to carry two types of steel would be of interest. If simulation could be used to quantify the difference between maintaining two lots of steel vice using the same steel for both DDG-51 and LPD-17, the Navy may pay more attention.

### **3.211 Summary**

Bath is a relatively small yard when compared to Ingalls. It struggles with waterfront and production area constraints. This is very similar to many of the Japanese yards. Constraints force management to properly plan each stage of construction. The initial phases of operations at Bath require some attention. The improvements planned

for the Hardings plant go a long way to becoming more efficient. The outfitting of blocks as observed in PO2 at Bath was the finest quality observed in all of the shipyard tours. Working in a controlled environment without the limitations of On Board outfitting is clearly a more efficient process than that observed at Ingalls.

The current order book at Bath allows management to make significant investments in infrastructure and process improvement. The required throughput to sustain BIW is not as high as at Ingalls. With proper streamlining of material flow and investments in new technology, BIW could come close to matching the quality and productivity of the Japanese.

### **3.3 - NASSCO, San Diego, California**

Areas of specific interest:

- Degree of Outfitting
- Material Control
- Rework
- Design Change Integration

#### **3.31 History**

NASSCO - National Steel and Shipbuilding Company is an employee owned major ship design, construction and repair facility. It was started as a small machine shop in 1905. NASSCO has built hospital ships, oil tankers, ferries, container ships, combat supply ships, tank landing ships, RO/RO and Oceanographic Research Ships. 25% of business devoted to overhaul and repair. In all NASSCO has delivered 296 ships evenly distributed between Navy and commercial work. NASSCO is a subsidiary of Morrison-Knudsen Company Inc.

Three major business areas include:

- Ship Repair and Conversion
- New Ship Construction
- Industrial and Offshore Fabrication

### 3.32 Financial Status

NASSCO is a employee owned company that is not a publicl traded company and so the financial data was not available. It was essentially rescued from bankruptcy by the US Government after major performance problems on the AOE-6 project. Performance on the converted T-AKRs was poor during the first stages of the project as well. As with any conversion, additional scope was found that needed to be scheduled. In hindsight it may have been more cost effective to build three additional three ships thus extending the product line to try to capture economies of scale. The reason the conversions were favored for the first group of ships was the expected short turn around time. This “quick fix” turned out to take much longer than anticipated and cost almost as much as the new construction ships.

Work on the New Construction T-AKRs has begun. Considerable learning was gained on the Sealift Conversion projects.<sup>46</sup> Better schedule and cost performance is expected on this contract.

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<sup>46</sup> Tedesco, M. (1997) Personal Communication

### 3.33 Current Navy and Commercial Work

The Navy Contracts NASSCO has in its yard is included in Table 3-9.

Ship Type	No.	Size	Customer	Value (Millions)	Delivery
AOE	1	19,700 lt	US Navy	365.8	10/97
T-AKR (C)	2	33,200 lt	US Navy	423.2	8/97
T-AKR	5	36,100 lt	US Navy	1,112.1	9/00

**Table 3-9 - NASSCO Order Book**

NASSCO relies on auxiliary and Sealift contracts from the Navy for its business. Recent developments include:

- Selected for Phase II consideration for the Arsenal Ship Program. Some concern within the Navy that NASSCO has not produced a combatant ship. This could prove to be an advantage if producibility features are emphasized. Teamed with Northrop/Grumman.

#### Commercial Ships

No current new construction work on the books.

Most recent commercial work includes:

- R.J. Pfeiffer, a 28,555 DWT open container ship for Matson lines in 1992
- Exxon Valdez and Exxon Long Beach 209,000 DWT tankers for Exxon in 1985.

NASSCO is better suited to building commercial ships than BIW or Ingalls. They have been the recipient of several MARITECH contracts for new ship designs including a crude carrier, a cruise ship and a trailer ship capable of transporting 500 truck trailers and

200 automobiles. Having a standard design that can be used “off the shelf” to satisfy a customer’s needs is a major strategic advantage to reduce costs and cycle times. The Japanese and Koreans use their marketing departments to push the standard shipyard designs. If American shipyards can produce world class designs, they may be able to draw more attention from world shippers.

### 3.34 Future Strategic Plan

*“By the year 2000 NASSCO will be the most effective designer and repairer of Navy and commercial ships, with at least one major international ship construction project; and will have a proven record of dramatic, ongoing improvement in our processes and products.”<sup>47</sup>*

- NASSCO is vying for commercial work including a 160,000 Dead Weight Tons (DWT) ARCO tanker and an even bigger 200,000 DWT B&P Tanker.
- Management is looking to win the next Navy auxiliary ship contract, ADCX. Significant producibility changes could be made on this ship to do things smarter and improve the Navy shipbuilding process. Auxiliary ships are more like commercial ships than warships so learning may be possible that may translate across platforms.

### 3.35 Shipyard Layout

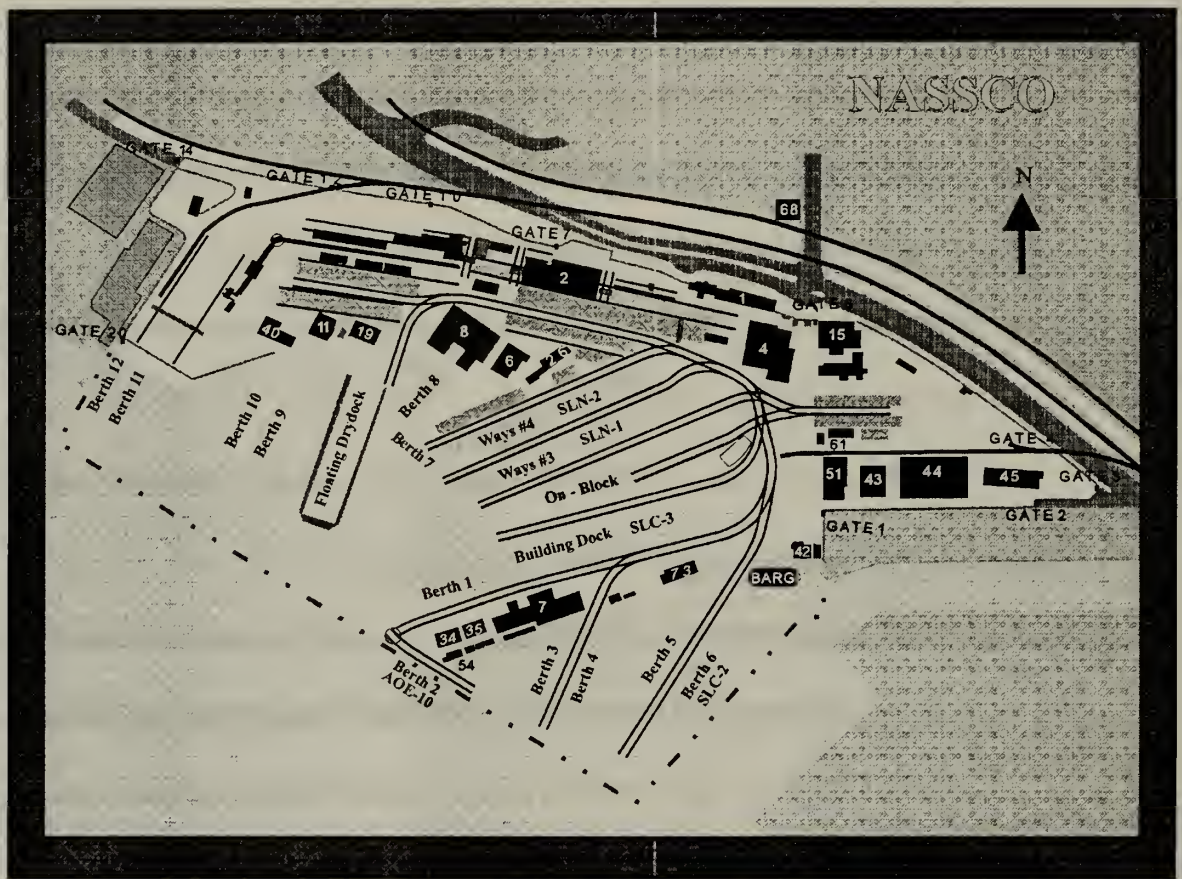
- Land Area - 147 acres of real estate
- Pier Space - 8 positions for outfitting and repair

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<sup>47</sup> NASSCO Vision Statement

- Crane Capacity - A Cranes - 3 with 90 ton capacity - limits erection blocks to 220 tons. B Cranes - smaller 40 ton cranes on rails. Cranes are used to move most of the blocks around the yard. This can interrupt work going on in the rest of the yard as the block passes overhead.
- Blast and Paint Facilities - NASSCO has sufficient capacity to support subsequent phases.
- Transfer Equipment - Overhead cranes are used exclusively to move the products around the shipyard.
- Capital for renovations - If any commercial work is contracted, investments will need to be made in several areas. NASSCO management has taken a wait and see attitude to improvements which is typical of US shipyards as a way to avert risk.
- Deep water access to the Pacific.
- 2 building ways and one dry dock for new construction.
- Dry dock used for tankers with high block coefficient. Not deep enough for finer ships.
- Major rail line brings steel and other material directly into the yard

Figure 3-15 depicts the shipyard layout at NASSCO.



**Figure 3-15 - NASSCO Shipyard Layout**

### **3.36 Human Resource Management**

- Current workforce of 5000 people. Peak as high as 7600.
- Assign a Project Manager for each program to provide interface with customer.
- Use modern effective information and control system to maintain clear visibility of all aspects of each program.
- Used to integrate engineering work requirements and schedules with manpower budgets, establish lead times for material procurement actions, and perform critical path scheduling including work around and recovery schedules.

- Gathers earned values and actual costs of work performed to produce schedule and cost variance analyses.
- NASSCO point to this method as a competitive advantage.

### **3.37 Production Planning**

NASSCO takes a manual approach to planning. The first step is to determine people required in different trades. They attempt to keep manning levels constant as they know trying to scale up quickly is expensive. Next the planners look at throughput rates and capacity at the different stages of construction to determine choke points. Finally, they look at crane capacity and equipment. There is currently no formal way of quickly assessing the impact of new work on the core business. Most of the structural steel work is done in the assembly stage and during On Board construction.

#### **Current Constraints:**

NASSCO is working at about 55% capacity. With present levels of manning NASSCO can produce approximately 12 blocks per week with 1.5 shifts. In order to increase the throughput, the first step is to hire more people. With the current infrastructure, production planners assume they can expand to 20 blocks per week without hitting another constraint.

At about 20 blocks per week, the constraint to production is the burning tables. Another table would be required to sustain 20 blocks/week. With a new table, NASSCO

could go to 22.5 blocks per week before they would need to invest in additional overhead crane capacity. Most of the lifts at the yard are conducted with 90 A cranes. These lifts consist of erecting, turning and moving. A smaller B crane would be needed first to allow the A cranes to concentrate on erection. The cost of these improvements and determining the cost-benefit relationship of investing in new infrastructure is a topic for future work

### **3.38 Phases of Construction**

#### **Detailed Design**

NASSCO maintains a strong design department. They have conducted several recent design efforts under MARITECH sponsorship on product and car carriers. They are trying to standardize the parts used to build the different ships in the yard. If the simplest parts of the ship are common, they may be able to reach economies of scale in early production. Managing the process of joining these common components into individual blocks becomes a harder challenge.

#### **Material Handling and Procurement**

- Most material comes by truck or rail
- There did not seem to be as much work in progress at NASSCO as observed at BIW. The products are very different. The DDG-51 is much more densely outfitted than the T-AKR.

- NASSCO is working to make Just in Time (JIT) a reality by coordinating timely deliveries from its suppliers.

### **On Unit Construction**

The outfitting process at NASSCO resembles that found at Ingalls. Much more outfitting is done in the On Board phase. As can be seen in Table 3-10, next to no work is done at this stage at NASSCO. The weather and space available at NASSCO do not force the processes inside. This may lead to degraded productivity and quality.

### **On Block Construction**

More of the outfitting is done here although still not to the level that Bath or some of the foreign yards achieve. No Final Blast and Paint is conducted prior to erection. Again, this is a function of both the process and the product at NASSCO. A T-AKR is a huge truck carrier. The cargo carried by the T-AKR does not come aboard until a crisis occurs. The DDG-51, on the other hand, is packed with weapons and electronics that allow it to operate before delivery to the Navy. Coordination of the higher degree of outfitting is more easily accomplished at earlier stages. The differences between ships are captured in a complexity factor.

NASSCO does not see the value in pre-outfitting to a greater degree with its current products and schedules. To increase throughput to the levels that would support building

commercial tankers, NASSCO will need to do more outfitting away from the erection sites.

### **On Board Construction**

Most of the Outfitting work is left to the On Board phase. As discussed in Chapter 2, this is the least efficient of the construction phases. Once the ship is on the ways or in the water, access to different spaces is extremely limited. The controlled environment and easy access to support services of the shop is not available. Interferences with other trades must be overcome.

A breakdown of how much of the ship is built at each of the different phases of construction is included in Table 3-10.

Phase of Construction	Percent of Work Done	
	Structural Steel	Outfitting
Planning - SOC 0	3%	4%
Fabrication - SOC 1	12%	16%
Sub Assembly - SOC 2	6%	1%
Assembly - SOC 3	41%	4%
On Unit - SOC 4	0%	1%
Block Outfit - SOC 5	4%	22%
On Board - SOC 6	33%	44%
Testing - SOC 7	1%	8 %

**Table 3-10 - NASSCO Stages of Construction**

### **3.39 Performance**

NASSCO experienced poor cost and schedule performance on the AOE contract for a variety of reasons. Cost growth on this program has been estimated at 30%. This resulted in the elimination of one ship from the contract to rescue the company from

bankruptcy. Basically the Navy paid the same amount of money for one less ship. Work has progressed more smoothly on the Sealift conversions and even better on the New Construction Sealift ships. Understanding the constraints of the yard is critical to being able to deliver at cost and on time.

### **3.310 Simulation**

NASSCO has been exploring the use of simulation in their yards. Some of the production people have been to Ingalls to visit the simulation group. NASSCO is not convinced strategic modeling will do anything for them. They have approached Decision Dynamics about the status of ShipBuild. There are many questions that arose during the visit that could be investigated using System Dynamics.

- First, NASSCO will need to greatly improve throughput in blocks per week if they are to smoothly work both Navy and commercial work. They are able to push about ten blocks per week through their yard with the present manning levels. Plans for ARCO tanker work indicate levels of 28 blocks per week will be required. NASSCO does not know if they can support this increase in throughput. They are bidding on new work that could put their base contract, the Navy Sealift ships, at risk. Based on their performance on the AOE-6 program running concurrently with the Conversion Sealift Ship, this increase in capacity is not realistic. It would be interesting to study the constraints within the yard using simulation to determine the constraints at each level.

- NASSCO went through a long battle with the Navy over delay and disruption on the AOE-6 program. This dispute resulted in the cancellation of one of the ships in the class. Perhaps a model similar to the Pugh Roberts Shipbuilding Model could have been used locally to determine how much of the delay and disruption was the fault of the contractor and how much was the fault of the Navy.
- NASSCO is trying to find a way to quantify the cost of internally generated change. They have been encouraging employees to provide suggestions for how to improve the process. Producibility issues play a large part in reducing costs and cycle times. The problem that exists is determining the cost of making a change to the design at a late stage in the contract. They have a formal billing system for customer generated change orders. There is no rapid and efficient way to do a cost benefit analysis for producibility issues.
- Every shipyard mentioned flattening manning levels as a crucial need in their yard. They understand that in times of little work, the easiest way to cut overhead is to lay people off. All also reported that hiring new people to support a new contract is expensive. NASSCO mentioned this specifically as a problem on the AOE-6. The Navy awarded NASSCO the task of converting 3 foreign container ships into Sealift assets for the US Army. This called for the hiring of additional personnel, especially structural steel workers. Productivity in the entire yard went

down for a considerable time as experienced people were moved to new jobs and new people were indoctrinated.

- Having dealt with large fluctuations in manning before, the senior management is looking for ways to keep their current workers gainfully employed until the next surge in work comes along.

### **3.311 Summary**

NASSCO is the largest shipbuilder on the West Coast of the United States. It has great potential to compete with the Japanese and Koreans on commercial ships if it can maintain a strong base of Navy work. The Navy ships it builds are more like commercial ships than any of the other yards visited. Learning across programs could be a valuable factor for improving productivity and quality.

If NASSCO management can get a better handle on the constraints of the yard, they may be able to make smart decisions about where and when to invest in infrastructure. The design staff is capable of producing commercial designs. It remains to be seen if these designs generate any commercial work.

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### **3.4 - Newport News Shipbuilding, Newport News, Virginia**

A detailed tour of Newport News was not possible during the limited time for this research. The preliminary information for NNS is included for completeness and will be updated when the opportunity arises.

Areas of Specific Interest include:

- Building Double Eagle Tankers in same yard as Nuclear aircraft carrier.
- Impact on overhead of other program in a nuclear capable yard
- Problems encountered with shipfitting on Double Eagles
- Renovations are needed to retool for NSSN
- Impact of diverse products in same shipyard
- Innovation Center for CVX

#### **3.41 History**

Newport News Shipbuilding (NNS) is the largest privately owned shipyard in the United States. It was recently spun off by Tenneco to become its own company.

The company was founded in 1886. NNS has delivered nearly 800 ships ranging from tugboats to super carriers. Famous ships produced at NNS include:

- Seven battleships of Teddy Roosevelt's Great White Fleet
- BG Texas and Pennsylvania
- Ranger - first US carrier built from keel up

- Passenger Liners America and United States - Fastest commercial ships ever built
- Enterprise - first nuclear aircraft carrier
- Los Angeles Class submarine
- Nimitz Class Carriers
- UST Atlantic, UST Pacific - largest ships built in Western Hemisphere

Newport News has become the sole provider of Nuclear Aircraft Carriers in the country

### 3.42 Financial Status

<b>NNS Financials (\$ millions)</b>	1996	1995	1994
Marine Engineering and Production Revenues	\$ 1908	\$1800	\$1753
Marine Engineering and Production Operating Profit	\$160	\$184	\$200
Profit Margin	8.4%	10.4%	11.4%
Revenues/Employee (\$000)	106	90	88

**Table 3-11 - NNS Financial Status**

As the Los Angeles submarine came to a close, more of the shipyard activity became lower margin conversion and repair work. NNS has a considerable backlog of work as will be outlined in the next section. Revenues per employee have been steadily increasing indicating increasing productivity per worker.

### 3.43 Current Navy and Commercial Work

Ship Type	No.	Size	Customer	Value (Millions)	Delivery
CVN	2	75,000 lt	US Navy	4,350	12/02
NSSN	2	7500 lt	US Navy	1,229.4	6/00
T-AKR	2	33,200 lt	US Navy	425.6	3/97
Product Carriers	4	46,000	Fleaves Shipping	152.0	2/98
Product Carriers	5	46,000 lt	Hvide	245.7	12/98

**Table 3-12 - NNS Order Book**

Navy Work:

- The bulk of NNS order book is made up of the 2 Nuclear Aircraft Carriers, CVN-75 and CVN-76. Plans are proceeding for CVN-77 as well.
- As the Los Angeles construction came to a close, NNS made a successful push to acquire some New Attack Submarine (NSSN) work. They are currently teamed with Electric Boat to produce next attack submarine.
- Conversion of 2 Strategic Sealift Ships, Gordon and Gilliland
- Overhaul of CVN-69

The commercial work at NNS is intriguing. The Double Eagle, Double Hulled Tankers are the first new construction double hulled ship built in a US shipyard that meet the requirements of OPA 90.<sup>48</sup>

- Mobil has recently purchased another of the Double Eagle tankers
- NNS may be taking a loss on the current commercial work hoping to generate niche market for double hull tankers produced domestically. If productivity can be improved using this work it may help future Navy construction costs as well.

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<sup>48</sup> Maritime Reporter and Engineering News, (1997) Mobil to buy NNS Tanker, February 1997.

### **3.44 Future Strategic Plan**

NNS has committed themselves to become the only nuclear shipbuilder in the country. They are currently investing in yard improvements including:

- Spending \$70 million for Automated Steel Factory used to modify steel fabrication capabilities using robotics and CAD/CAM technology
- Reconfiguring yard to build New Attack Submarine
- \$28.5 million to increase the length of the longest dry dock to 2173 ft

CVX is the next big prize on the horizon. Current plans call for a less expensive, possibly conventionally powered carrier. This could introduce competition to the carrier market for the first time in 30 years. NNS is utilizing its innovation center to ensure it remains the primary player in any new aircraft carrier contracts.

NNS made a concerted effort to build commercial ships after 15 years. Many people say they are losing their shirts on this contract. NNS seems to feel the commercial experience will pay great dividends down the line. How do they know this is not a wasted effort? There have been rumors of many problems on the contract. The oversight of dealing with Navy nuclear ships may have priced the yard out of commercial competition. It will be interesting to see what happens with this effort.

### **3.45 Shipyard Layout**

- Land Area - 550 acres along James River near port of Hampton Roads
- Pier Space - Eight Dry Docks, floating dry dock, four piers
- NNS is the largest of US Shipyards in terms of capacity and work force.



### **3.5 Avondale Shipbuilding**

Only a quick tour of Avondale was possible. The details of the yard will be fleshed out in later visits.

#### **3.51 History**

Avondale Industries is an employee owned company under an Employee Stock Ownership Plan (ESOP). Avondale is a diversified company consisting of several subsidiaries including the Shipyards, Modular Construction, Steel Sales, Boats, and IPDE Technology Divisions. Avondale's Shipyard Division was founded in 1938 by two ex river boat captains as a barge construction and repair facility. In 1959, Avondale was purchased by Ogden Corporation. It remained part of Ogden Marine until 1987 when the ESOP purchased the company.

#### **3.52 Financial Status**

<b>Avondale Financials (\$ millions)</b>	<b>1994</b>	<b>1993</b>	<b>1992</b>
Marine Engineering and Production Revenues	\$475.8	\$456.7	\$576.4
Marine Engineering and Production Operating Profit	\$16.9	\$3.4	\$7.2
Profit Margin	4%	1%	1.5%
Revenues/Employee (\$000)	83	91	89

Table 3-13 - Financial Data at Avondale

### 3.53 Current Navy and Commercial Work

The order book at Avondale is listed in Table 3-14.

Ship Type	No.	Size	Customer	Value (Millions)	Delivery
LSD	1	11,900 lt	US Navy	257	4/98
WAGB	1	15,000 lt	USCG	232.2	6/98
LPD	1	18,000 lt	US Navy	641.1	7/02
T-AKR	5	34,400 lt	US Navy	1,102.7	1/00
Product Carriers	2	38,000	AHL	71.5.0	7/97

Table 3-14 - Avondale Order Book

### 3.54 Future Strategic Plan

Avondale has established itself as the premiere builder of Amphibious ships in this country. They also continue to push for commercial work. Investment in infrastructure continues. Avondale has doubled the capacity of its Blast and Paint Facility, increased On Unit and Fabrication capacity in the “Ship Module Factory.” A better material handling and control system will need to be put into place to make the shipyard more efficient. There is an excess amount of storage space and warehouses in the yard indicating much work in progress. Avondale may need to make similar changes as BIW to its MRP system if they want to become as productive as the foreign competition.

### 3.55 Shipyard Layout

The layout at Avondale is shown below.

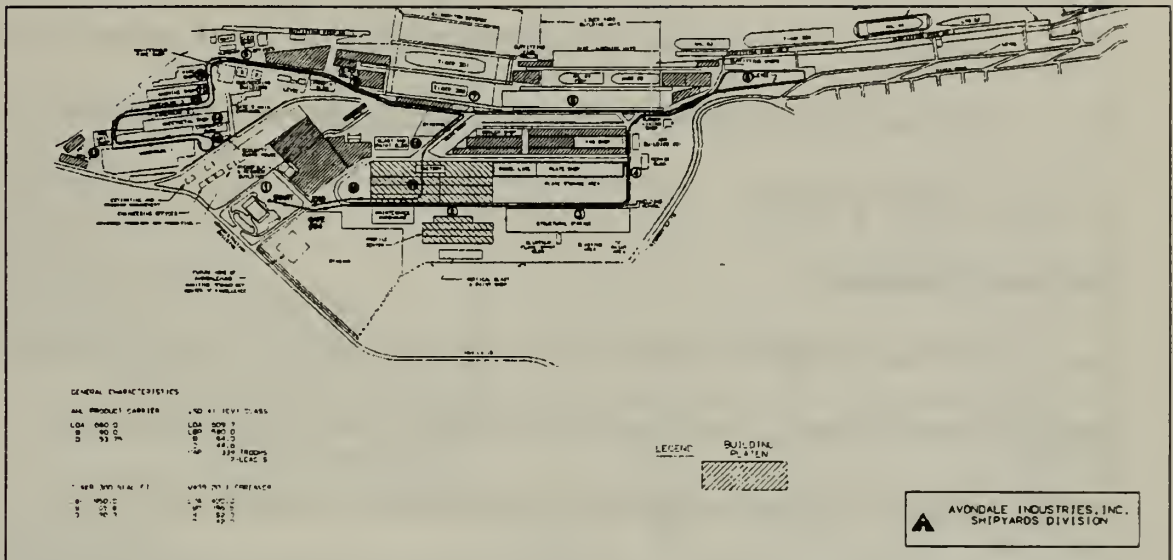


Figure 3- 17- Avondale Shipyard Layout

Key Factors include:

- Land Area - 268 acres
- Upper Shipbuilding area capable of constructing ships up to 250,000 dwt or 3 conventionally sized ships concurrently. The limitations of the dry dock is 81,000 lt.
- Pier Space - 3 outfitting piers for a total of 6000 linear ft
- Crane Capacity - 600 ton floating crane, 250 ton turnover rig, 250 ton, 150 ton, and 100 ton outfitting cranes,
- Blast and Paint Facilities
- Transfer Equipment: Blocks are moved around the yard using movable cranes and Heavy LO/LO trucks with a capacity of 250 tons. At the erection site, a

land a series of 280 ton jacks are used to move the completed ship into position for launch. It takes almost eight hours to move the ship into position. Ships constructed in the upper shipbuilding area move laterally in three positions for launching by the large floating dry dock. Ships built in the lower yard are moved laterally and parallel toward the river and side launched from one of 5 positions.

### **3.56 Use of Simulation**

Avondale is interested in exploring the impact of commercial and government work in the same shipyard. Many people in the industry feel the two products are mutually exclusive. The same workforce cannot do both. Avondale and NNS are currently attempting both. Avondale would like to know if workers can be used across programs effectively or if they should be separated into two worker pools. Being able to cross programs allows the shipyard managers much more flexibility to keep people at work. This practice may also lead to productivity improvements in Navy work.

## **3.6 Summary**

This section examines the differences between the yards visited. The strategic variables used to simulate each yard are presented in Table 3-15. The values in this table are the result of observations, publicly released information and educated guesses. They do not represent the exact values at any given time in these shipyards and should be used for comparison purposes only. Some data is left blank for future research. As this work continues, more detailed information will be gathered leading to more accurate results.

Shipyards Parameters	Bath	Ingalls	NASSCO	NNS	Avondale	
Labor	7500	11000	5000	18000	4500	
Peak Labor	10000	25,000	7600	30000	9000	
Max Labor (Phase)	Design (people)	250	200	250	300	350
	Fabrication(people)	500	850			
	On Unit(people)	500	850			
	On Block(people)	500	850			
	On Board(people)	500	850			
Outfitting Piers	4	3	8	4	3	
Total Shipyard Area (acres)	55	788	147	550	268	
Pre-outfitting	73%	65%	60%	65%	60%	
Design Capacity (blks/wk)	3	2	3	4	6	
Current Infrastructure Limits (blks/wk)	2	12	20		35	
	B&P (blks/wk)	2	8	10		35
	Fabrication Equipment (blks/wk)	8	12	20		35
	On Unit Area (blks/wk)	8	25	23		35
	On Block Area (blks/wk)	6	30	25		40
	Erection Area (blks/wk)	8	30	25		40
Cranes (block size)	220	300	250	300	250	
Erection Sites (active)	2	6	3	9	8	
Erection Site Limitations - Length (m)	260	270	310	400	310	
Erection Site Limitations - Weight (lt)	30,000	30,000	200,000	200,000	250,000	
Erection Site Limitations Draft (m)	7	6	5	8	7	
Dry Dock Capacity (lt)	30,000	30,000	200,000	200,000	81,000	
Capacity Utilization	75%	30%	55%	40%	50%	
Current Throughput (blks/wk)	2	4.5	12	10	18	

Table 3-15 - Shipyards Strategic Variables

## Chapter 4 - Production Model Description

In this chapter, the Build Strategy for the SOCV and the shipyard characteristics of Chapter 3 are used to create a System Dynamics model that is used to manage the planning and construction process of SOCV. The model is used to increase understanding and facilitate insights concerning the complexities of the project. Shipbuilding consists of large, complex, capital intense projects. Shipbuilders consider prototyping too expensive. Because of this, shipbuilding is a natural field for use of simulation. 3-D product models of the ship allow many of the uncertainties involved with the ship design to be examined virtually. Likewise, the process used to build the product can be simulated. The experience gained using a simulation run many times will prove invaluable to managers when they need to make real decisions.

Any large scale construction project demonstrates the following characteristics which tend to make them harder to manage:

- Complex material flows, consisting of multiple interdependent components
- Dynamic behavior, not constant over time
- Nonlinear relationships
- Feedback between and feed forward
- “Hard” and “soft” data<sup>49</sup>
- Many factors operating simultaneously

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<sup>49</sup>Sterman, J.D., (1992), “System Dynamics Modeling for Project Management”, unpublished working paper, Systems Dynamics Group. Sloan School of Management. Massachusetts Institute of Technology.

In support of this work a System Dynamics project model is developed to represent the shipbuilding process. The model is tuned to capture the specifics of Ingalls shipbuilding. The analysis conducted in Chapters 3 and the Build Strategy Document provide the basis for calibration to represent shipbuilding at Ingalls. This model has been developed for proof of concept. The level of aggregation is high enough to allow several case studies to be conducted relatively quickly. It is also detailed enough to capture project dynamics as observed during the shipyard visits. Additional calibration, using historical data and field observation, will be required to produce a model which can be used to accurately predict project performance for cost and schedule. This model is valuable for the behavior it can simulate and not for exact values. It can be used to test the impact of certain policies and their relative magnitude.

The first task when building a System Dynamics model is problem identification and model conceptualization. *"In constructing a useful model of corporate behavior, it is essential to have clearly in mind the purposes of the model. Only by knowing the questions to be answered can we safely judge the pertinence of factors to include in or omit from the system formulation."*<sup>50</sup> The purpose of the Ship Production Model is to provide a broader systems perspective for managers involved in the acquisition process for SOCV, both in the government and in the private sector. The model supplements the static planning programs of Critical Path Method (CPM) and Probabilistic Evaluation and

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<sup>50</sup>Sterman, J.D., (1992), "System Dynamics Modeling for Project Management", unpublished working paper, Systems Dynamics Group. Sloan School of Management. Massachusetts Institute of Technology.

Review Techniques (PERT) that are so widely used in ship construction. It captures the dynamic features of feedback and prerequisite dependencies found in the shipbuilding process. Once the Ship Production Model is complete, a base case can be developed. The base case represents the present state of the way Ingalls build ships. The model can be modified to represent any shipyard. The base case is used as a benchmark from which policy analysis is conducted. The Ship Production Model is then used in Chapter 6 to examine the differences between two shipyards and several process issues which may improve the performance of the project. Each issue was mentioned specifically by the shipbuilders as a concern for which they did not have the tools to examine.

#### **4.1 Model Development**

The Ship Production Model uses previously developed work to identify the key structures found in most projects. Additional structure is then added to capture the specific attributes of shipbuilding. The reference modes and dynamic hypotheses for project structures can be found in several works including *Industrial Dynamics*<sup>51</sup>, *System Dynamics Modeling with Dynamo*<sup>52</sup>, and the *Vensim User's Guide*<sup>53</sup>. The key structures used in the Ship Production Model are identified in this section. Several of the table functions used in this model were developed in other studies including the *Effect of Overtime on Productivity and Quality*.

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<sup>51</sup> Forrester, J.W. (1961), "Industrial Dynamics", Cambridge, MA, Productivity Press.

<sup>52</sup> Richardson, G.P. and Pugh, A.L., (1982) "Introduction to System Dynamics Modeling with DYNAMO," Productivity Press, Portland, Oregon.

<sup>53</sup> Vensim User's Guide, (1995) "Ventana Simulation Environment", Ventana Systems Inc.

## 4.11 Previous Project Models

System Dynamics Project Models were first envisioned by Jay Forrester at the Sloan School of Management in the early 1960's. Several of his students have used Project Models to gain insight in many industries.<sup>54</sup> Similar structures for Project Models have been developed and tested in previous studies. Some models, described in the literature search, can represent the shipbuilding process. A brief summary of the project models most suited for shipbuilding and the structures they introduced is listed below:

- Roberts - 1974 - First research and development project model. Introduced work flow based on productivity and manpower, management decisions, and perceived and actual progress.
- Cooper - 1978 - First large scale use of project model. Model of the Ship Production process used for claims settlement. The model focused on rework caused by customer changes. Key structures include rework, downstream dependencies, overtime, defect discovery time and quality. Concepts introduced include:
  - Customer can influence cycle times and scope of work
  - There is a distinction between first and higher order impacts
  - Competition among activities for resources.

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<sup>54</sup> Ford, D. N., (August 1995), "The Dynamics of Project Management: An Investigation of the Impacts of Project Process and Coordination on Performance," PhD Thesis. Sloan School of Management. Massachusetts Institute of Technology. Cambridge, MA.

- Richardson and Pugh - 1981 - Developed System Dynamics Textbook. Created a small project model including real progress, undiscovered rework, perceived progress, effort perceived remaining, hiring, and scheduling.
- Abdel-Hamid - 1984 - Modeled software development which contains many structures similar to shipbuilding.
- Homer - 1993 - Built project models using constraints of available work and infrastructure to limit production. Also introduced fatigue as a human resources issue.
- Ford - 1995 - Points out that the structure of static planning models have not been effectively coupled with dynamic feedback. Attempts to bridge the gap. Developed multi-phase product development model with down stream constraints for the computer manufacturing industry.
- Alfeld - 1996 - Shipbuild - starts as production planning model. Adds feedback and causal loops after static plan is established. Still under development but holds much potential as a commercial package.

Many of the structures used in these models were developed for different industries and are tailored for Shipbuilding. Additional structure is taken from the Molecules of Structure developed by Jim Hines and merged by Bob Eberlein into the System Dynamics modeling software package, Vensim.<sup>55</sup>

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<sup>55</sup> Hines, J., (1996), Molecules of Structure - Building Blocks for System Dynamics Models”, Leaptec and Ventana Systems.

#### 4.12 Ship Production Model Characteristics

The Ship Production model consists of several interacting sectors. These include the following:

- Multi Phase Work Accomplishment and Rework -
- Labor Adjustment - Project Labor adjustment and Shipyard Hiring and Firing
- Schedule Completion
- Financial
- Quality Effects
- Productivity Effects
- Shipyard Constraints

Each sector will be discussed in greater detail in the following sections. Multiple phases are modeled with inter-phase dependencies. These phases are consistent with the Build Strategy developed for SOCV and are listed below.

- Design
- Fabrication
- On Unit Construction
- On Block Construction
- On Board Construction

The next step in the progression of this model would be to tune it to match the Product Work Breakdown Structure (PWBS) currently being proposed by NSWC Carderock as a standard for the industry. With common production sequence, each yard could be compared directly

Three types of constraints limit the work accomplishment in the model.

- Labor - limited to 200 shipyard designers and 850 production people per ship
- Process constraints between phases - Early portions of ship must be built before the later portions. Must have panels with frames and strakes before we can mount the machinery foundations. We must have the foundations in place prior to landing the main engines.
- Facilities - Engineering Work Stations, Building Ways, Lift Capacity, Covered Manufacturing Space, Assembly Area, and Blast and Paint all act to constrain the flow of material through the yard. These hard constraints should not be allowed to effect production although in some yards they do. Management should be able to control the rate of work based on the workforce. These constraints cause managers to react and are included in the model to determine there impact on the process. When hard constraints are experienced, investment in additional infrastructure should be made. Quantifying the benefits of investment in infrastructure is one of the primary purposes of this model

#### **4.13 Model Features**

The scope of the problem is defined by the boundaries chosen for any model. For this reason it is critical to identify the boundaries. The level of aggregation is also important to identify. In order to make a model sufficiently compact, some simplifying

assumptions must be made. Every detail of the shipbuilding process can not be included in the model. The point at which aggregation begins depends on the purpose of the model. The boundaries of this model are depicted in Figure 4-18. The purpose is to concentrate on those aspects the shipyard has under their control.

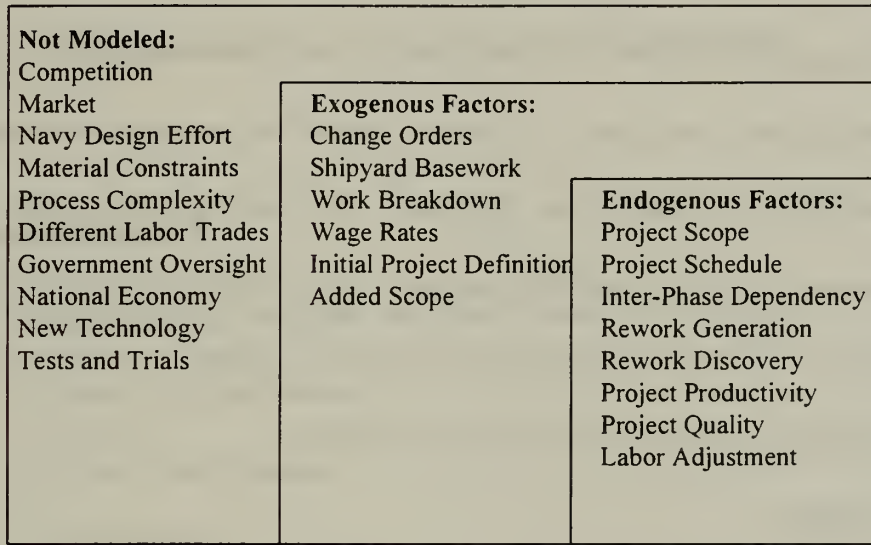


Figure 4-18 Model Boundaries

For this model, all construction work starts out as drawings and raw stock. From these basic components, parts are either manufactured or purchased from an outside source. All material is assumed to be ordered and delivered in time to support the process.

These parts are combined to form units of structural steel and subsystems in the first assembly stage. The outfit units and steel units are brought together with additional drawings for assembly and outfitting guidance to form erection blocks. The blocks are combined at the erection site to form the finished product, the ship. Additional outfitting

is done at the erection site. The amount of parts used to make a unit is an average of all the units. Likewise the blocks use an average number of units and drawings. Finally the ship is erected from the blocks in a sequence identified in the Build Strategy.

This model is much more closely aligned to the Build Strategy of a new ship than any other shipbuilding project model. It is being used to find problems before they occur instead of assessing blame after the fact. It contains many of the internal precedence and constraints planned for incorporation into Shipbuild. The work profile and the cycle times are true representations of a real ship program. The determination of how many blocks are needed is formed using the Build Strategy in Appendix A. The shipyard infrastructure and labor constraints are determined in Chapter 3.

Specific features include:

- Rework is modeled as iteration required to be done based on the shipbuilder's definition of quality
- Customer driven design changes are modeled as increased scope and plugged into rework sector
- The Financial Sector determines overhead rate, unit costs, and project performance in terms of cost and schedule.
- The Schedule Sector is used to calculate Willingness to Change Workforce and Schedule Pressure. These are dynamic decisions based on how far along the project has progressed. The Schedule sector is also used to determine whether the project is ahead or behind schedule.

- Productivity is a function of Schedule Pressure, Phase of Construction, Fatigue and Work Force Experience.
- Quality Goal is a management policy decision but is affected by many of the same factors as productivity.
- Base Work is a function of attractiveness against industry competitors and project performance. In this model it will be exogenous.

## **4.2 Model Structure**

The Ship Production Model consists of 7 sectors. They are:

- Work Flow and Rework
- Labor Determination
- Productivity
- Quality
- Phase Initiation and Schedule
- Financial
- Shipyard Constraints

The equations used in each sector are discussed below. The full set of equations are found in Appendix B.

## 4.21 Multi Phase Work Flow and Rework Sector

The Work Accomplishment core structure comes from the Molecules of Structure<sup>56</sup>. This structure is the core of any project model. The components of the Work Accomplishment sector are shown in Figure 4-17.

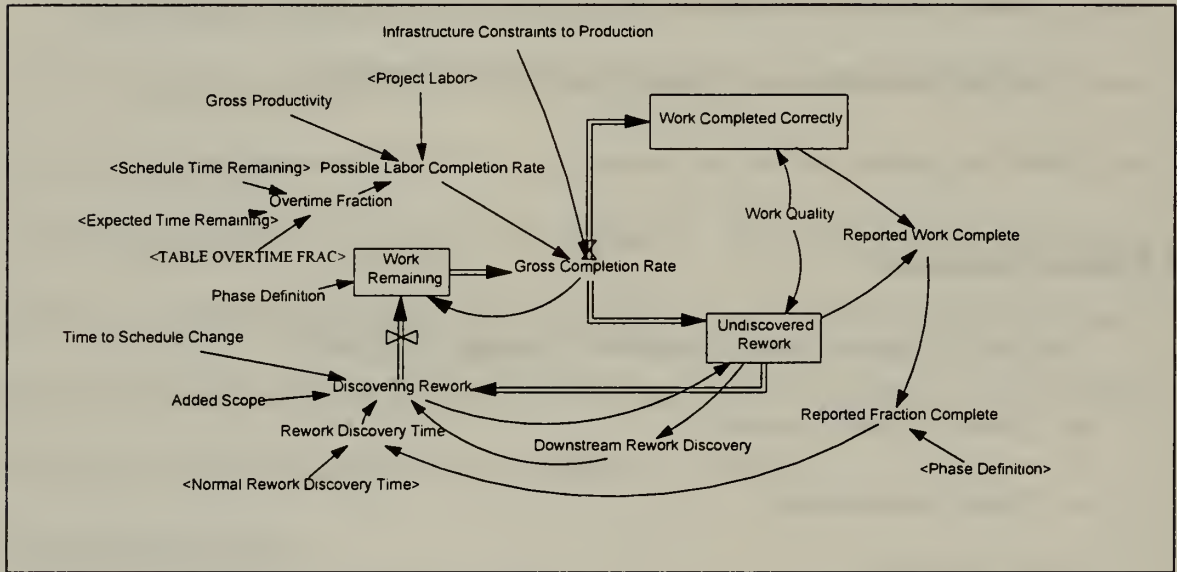


Figure 4-19 - Work Accomplishment Sector

<sup>56</sup> Hines, J.H., (1996), "Molecules of Structure - Building Blocks for System Dynamics Models," Leaptec and Ventana Systems.

A description of the flow of work through the model starts with the initial conditions for the project. Phase Definition is an exogenous variable based on the required work content set by the Build Strategy. The work is broken out by phase of construction. The amount of work done in each stage is a strategic decision based on the constraints of the shipyard. The magnitude of work conducted in each phase represents the way Ingalls currently builds ships.

*Phase Definition[phase] =Design(12500),Fabrication(39726),On Unit(8680),On Block(17187),On Board(36902) work orders*

A work order represents the smallest of the tasks needed to build a ship consisting of 20 hours of work. This is the smallest increment of work that is tracked at several shipyards. To go to finer detail does not match up with how progress is currently reported in the yards. Some shipyards would like to go to reporting of progress in a more timely fashion. When this happens, the smallest unit can be adjusted accordingly.

The Work Remaining is a level. The initial value is set by Phase Definition. The level is reduced by the Gross Completion Rate. The flow of Discovered Rework and Added Scope contribute to the Work Remaining. The value of Work Remaining at any time is the integration of the difference in these two flows.

$$\text{Work Remaining}[\text{phase}] = \text{INTEG}(\text{Discovering Rework}[\text{phase}] - \text{Gross Completion Rate}[\text{phase}], \text{Phase Definition}[\text{phase}])$$

The Gross Completion Rate is a flow which is affected by Productivity, Project Labor, and Constraints to Production. The work completion rate is the minimum of either the labor or infrastructure constraints. If the amount of work to be done is zero, the Gross Completion Rate returns a value of zero as well.

$$\text{Gross Completion Rate}[\text{phase}] = \text{IF THEN ELSE}(\text{Work Remaining}[\text{phase}] > 0, \text{MIN}(\text{Infrastructure Constraints to Production}, \text{Possible Labor Completion Rate}[\text{phase}]), 0)$$

The work is either completed correctly or becomes Undiscovered Rework based on the Quality of the project. Quality is a strategic variable determined initially by the shipyard. Several factors, discussed later affect the value of quality.

$$\text{Work Completed Correctly}[\text{phase}] = \text{INTEG}(\text{Gross Completion Rate}[\text{phase}] * \text{Work Quality}[\text{phase}], 0)$$

$$\text{Undiscovered Rework}[\text{phase}] = \text{INTEG}(\text{Gross Completion Rate}[\text{phase}] * (1 - \text{Work Quality}[\text{phase}]) - \text{Discovering Rework}[\text{phase}], 0)$$

Correct Work and Undiscovered Rework are both Reported Work Complete.

$$\text{Reported Work Complete}[\text{phase}] = \text{Work Completed Correctly}[\text{phase}] + \text{Undiscovered Rework}[\text{phase}]$$

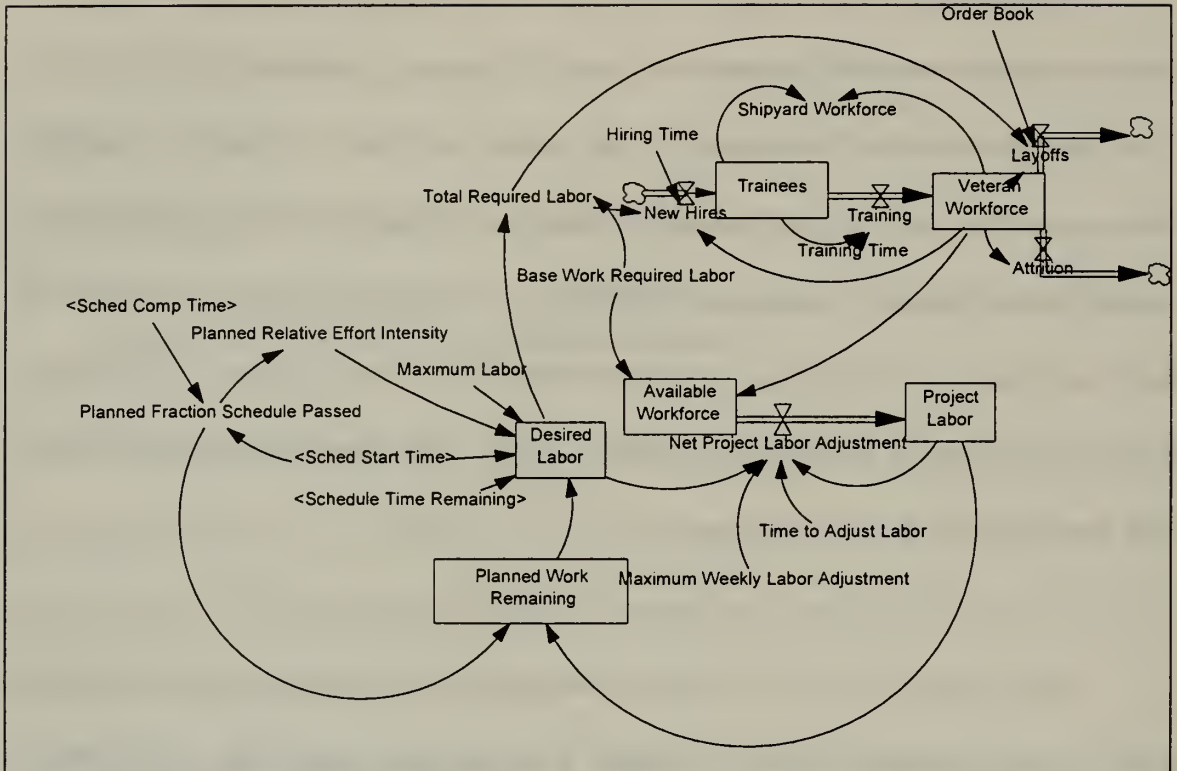
Faulty work that needs to be redone is uncovered by Rework Discovery in both the current phase and with Downstream Rework Discovery. In-phase discovery can be done by the workers themselves or by people assigned to Quality Assurance. Downstream Discovery is usually done by workers in the next phase who find the inputs to their process lacking. Downstream Discovery is affected by how long it takes for the faulty equipment to be or drawing to be incorporated into the next phase. For the Design it may take as long as six weeks to find the problem. The Undiscovered Rework feeds back in to Work To Do after it is found.

Any Change in Scope to the project generated by the customer or internal needs is added to the Discovered Rework. Change in Scope goes through the same Time to Schedule Change as Rework for proper integration into base work.

$$\text{Discovering Rework}[\text{phase}] = \text{MAX}(0, \text{MIN}(\text{Undiscovered Rework}[\text{phase}] / \text{TIME STEP}, \text{Undiscovered Rework}[\text{phase}] / \text{Rework Discovery Time}[\text{phase}] + \text{SUM}(\text{Downstream Rework Discovery}[\text{downstream!}, \text{phase}])) + \text{Added Scope}[\text{phase}] / \text{Time to Schedule Change}$$

$$\text{Downstream Rework Discovery}[\text{downstream}, \text{phase}] = \text{IF THEN ELSE}(\text{Phase is Active}[\text{downstream}] : \text{AND: Prerequisite Dependency}[\text{downstream}, \text{phase}], \text{Undiscovered Rework}[\text{phase}] / \text{Prerequisite Rework Discovery Time}[\text{downstream}, \text{phase}], 0)$$

## 4.22 Labor Adjustment Sector



**Figure 4-20 - Labor Determination**

The Project Labor is a level which is adjusted using the Net Project Labor Adjustment. Labor is added and subtracted from the project based on the Desired Labor of the phase. A certain amount of Time to Adjust Labor is required to make labor adjustments. This represents the time to either indoctrinate shipyard personnel to the project or release people back to the labor pool. Additionally, the number of people that can be added or subtracted from a program during one week is capped by the Maximum Weekly Labor Adjustment.

$$Project\ Labor[phase] = INTEG(Net\ Project\ Labor\ Adjustment[phase], Desired\ Labor[phase])$$

*Net Project Labor Adjustment[phase] = MIN(Maximum Weekly Labor Adjustment[phase], (Desired Labor[phase] - Project Labor[phase])/Time to Adjust Labor[phase])*

*Maximum Weekly Labor Adjustment[phase] = 50 people/week*

*Time to Adjust Labor[phase] = 3 weeks*

The Available Workforce is a stock which represents the pool of qualified people in the yard available to work on new ship projects. The initial value is the difference between Base Work Required Labor and the Veteran Workforce. Adjustments to the Available Workforce are then made by the Net Project Labor Adjustment for each phase of work depending on the manpower needs of the phase.

*Available Workforce[phase] = INTEG(-Net Project Labor Adjustment[phase], Veteran Workforce-Base Work Required Labor)*

The Base Work Required Labor is an exogenous variable which represents the number of people in the shipyard working on base work. At Ingalls, the Base Work in the yard includes the production of DDG-51 and LHD-1, as well as Arsenal Ship design work

*Base Work Required Labor = 8000 people*

The Veteran Workforce is a stock representing the number of trained workers available to meet the Order Book of the shipyard. The initial value for the yard is set at 11,000 people. This Workforce is reduced by Normal Attrition and Layoffs. It is increased by newly trained workers after a Training Time. This Training Time can be as long as 2 years for some trades. It is set as an average training time of nine months.

Attrition is set at approximately 10 % per year. This is the typical number of people who leave Ingalls every year for a variety of reasons including retirements disciplinary terminations and voluntary separation. Layoffs, involving the reduction of productive labor, occur based on the labor needs of the shipyard.

$$\text{Veteran Workforce} = \text{INTEG}(\text{Training}-\text{Attrition}-\text{Layoffs}, 11000)$$

$$\text{Layoffs} = \text{IF THEN ELSE}(\text{Order Book} < 2, \text{Veteran Workforce} - \text{Total Required Labor}, 0)$$

$$\text{Total Required Labor} = \text{SUM}(\text{Desired Labor}[\text{phase!}]) + \text{Base Work Required Labor}$$

$$\text{Attrition} = \text{Veteran Workforce} * 0.002$$

The Veteran Workforce is increased by the flow of new people being trained. A period of 4 weeks is required to acquire New Hires representing the delay in recruiting new workers. Additionally, it takes 9 months for a Trainee to become a productive worker through Training. The stock of Trainees is emptied by Training. Only the Veteran Workforce can provide suitable labor for the project. The Total Shipyard Workforce is the sum of the pools of people in Trainees and Veteran Workforce. This value is used to determine the Overhead Rate in the Financial Sector.

$$\text{New Hires} = \text{IF THEN ELSE}(\text{Veteran Workforce} \geq \text{Total Required Labor}, 0, (\text{Total Required Labor} - \text{Veteran Workforce}) / \text{Hiring Time})$$

$$\text{Hiring Time} = 4$$

$$\text{Trainees} = \text{INTEG}(\text{New Hires}-\text{Training}, 0)$$

$$\text{Training} = \text{Trainees} / \text{Training Time}$$

*Training Time = 36 weeks*

*Shipyards Workforce = Trainees + Veteran Workforce*

The Desired Labor of the phase is used to adjust the Project Workforce. It is the minimum of the Maximum Labor allowed for each phase and the Planned Work Remaining over the Normal Productivity times the Scheduled Time Remaining. It also takes into account the Planned Relative Effort Intensity. This allows a smooth ramp up and ramp down of the work force. Without using a planned intensity, labor adjustments at the beginning and end of the project are erratic and tend to overshoot what is actually required.

*Desired Labor[phase] = MIN(Maximum Labor[phase], IF THEN ELSE(Time + Time to Adjust Labor[phase] >= Sched Start Time[phase] :AND: :NOT:Phase is Done[phase], XIDZ((Planned Work Remaining[phase] / Normal Productivity[phase])\*Planned Relative Effort Intensity[phase], Schedule Time Remaining [phase], Maximum Labor[phase]), 0))*

*Maximum Labor[phase] = 200,850,850,850,850 people*

#### **4.23 Phase Initiation and Schedule Completion**

The planned completion time of each phase is established by the Build Strategy and the Schedule of Events in Appendix A. Phase Initiation depends on prerequisite tasks being completed to a satisfactory level. Shipbuilding in the past was an entirely linear construction process much like building a skyscraper. In the last 20 years it has evolved into a much more modular process with much of the ship being built in smaller packages and then erected into the entire ship. More concurrence is possible between phases thus reducing the total amount of time needed to build the ship.



$$Time + Expected\ Time\ Remaining[phase], Sched\ Comp\ Time[phase])$$

$$Initial\ Phase\ Length[phase] = INITIAL(Initial\ Schedule\ Completion\ Time[phase] - Initial\ Schedule\ Start\ Time[phase])$$

The Schedule Time Remaining is used to determine how much time is left to do the project work. If the project runs into trouble, the managers can do several things to correct for project deficiencies:

- Slip the schedule to the right
- Increase the labor working on the project
- Work overtime with the existing workforce

All of these options have an associated cost. Based on observations in the shipyards, all are used. Determining which is the most effective policy or combination of policies is very difficult. Each case can all be simulated using the model depending on what policy management chooses. In this sector the schedule slippage formulation is depicted. It depends on the Schedule Time Remaining.

$$Schedule\ Time\ Remaining[phase] = MAX(0, Sched\ Comp\ Time[phase] - Time)$$

The schedule is allowed to slip to the right if the expected completion date exceeds a certain limit. Several factors must exist for a slip in schedule to occur. Schedule Slippage is only allowed for the last 12 weeks of the project. This is a management decision that can be modified. The schedule is slipped in discrete increments when needed.

$$Scheduled\ Start\ Slip\ Time[phase] = IF\ THEN\ ELSE(Phase\ is\ Active[phase] :OR: VMIN(Prerequisites\ in\ Place[phase,prereq!]) > 0 :OR:(Time + TIME\ STEP < Sched\ Start\ Time[phase]) , 0, Start\ Slip\ Trigger\ Increment/TIME\ STEP)$$

*Sched Comp Time Slip[phase] = Scheduled Start Slip Time[phase] + IF THEN ELSE(Phase is Active[phase] :AND:Schedule Time Remaining[phase] < SLIP ZONE :AND:Expected Time Remaining[phase] - Schedule Time Remaining[phase] > SLIP TRIGGER, SLIP INCREMENT/TIME STEP,0)*

When the prerequisite tasks required to proceed to the next phase are completed to a certain level, the process is allowed to move to the next phase.

*Prerequisites in Place[phase,prereq] =IF THEN ELSE((Prerequisite Dependency[phase, prereq] = 0) :OR:Reported Fraction Complete[prereq] > Prerequisite Required Fraction Complete,1,0)*

The amount of time the schedule is slipped, if it needs slipping.

*SLIP INCREMENT = 4*

The amount of time behind schedule at which the completion date will be slipped.

*SLIP TRIGGER = 8 week*

The distance from the end of a project at which schedule slippage becomes an alternative.

*SLIP ZONE = 12 week*

The slip increment for starting a phase up if things are behind schedule

*Start Slip Trigger Increment = 0.5 week*

The fraction of the schedule that has passed adjusts itself in response to schedule slippage.

*Fraction Schedule Passed[phase] = IF THEN ELSE (Time > Sched Start Time[phase], IF THEN ELSE(Time < Sched Comp Time[phase],(Time - Sched Start Time[phase])/(Sched Comp Time[phase] - Sched Start Time[phase]),1),0)*

Several Equations are used to determine what part of the project is active and when they can be finished. Each phase is turned on at the Scheduled Start Time if the prerequisites are in place. Flags are used to indicate whether the phase is active or completed by returning a value 1 or a 0.

*Phase is Started[phase] = IF THEN ELSE(Time >= Sched Start Time[phase],1,0)*

*Phase is Active[phase] = IF THEN ELSE(Phase is Started[phase] :AND: :NOT: Phase is Done[phase], 1, 0)*

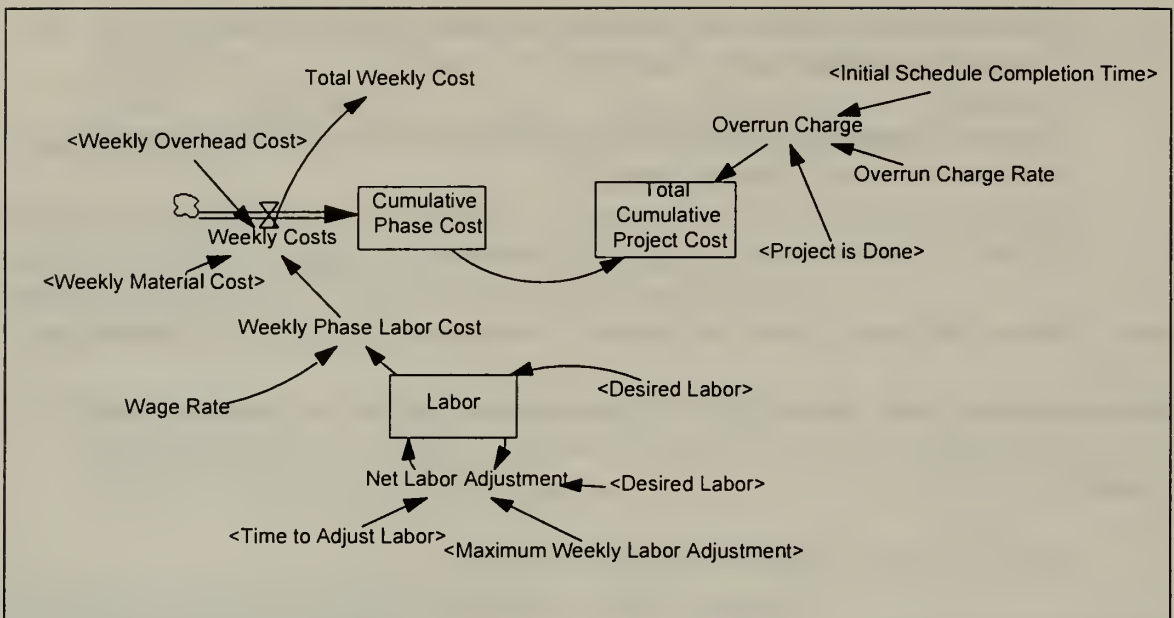
*Phase is Done[phase] = IF THEN ELSE(Reported Fraction Complete[phase] > Required Fraction Complete[phase], 1, 0)*

Project is Done represents a flag to indicate that the project is completed. Once the On Board outfitting is done, the project is completed. In reality, the project would require extensive trials and testing. For this model, the project is completed once all the planned work is done.

*Project is Done = Phase is Done[ONBOARD]*

#### **4.24 Financial Sector**

The Financial Sector is used to track project performance for cost. The Weekly Costs are determined based on the number of people working on the project. The Overhead Costs are determined by the total number of people working in the shipyard. Charges for Schedule Overruns are also modeled. Material costs are also included as a percentage of labor costs for simplification. These charges all add up to the total project cost.



**Figure 4-22 - Financial Sector**

Weekly Costs are determined by the Labor Costs and the Overhead Costs. The Labor Costs are determined by the Project Labor times the average weekly labor rate for the yard. The Weekly Overhead Costs are a function of the total number of people employed by the yard and the infrastructure available. The weekly costs for each phase are summed to determine the Total Weekly Costs.

$$\text{Weekly Phase Labor Cost}[\text{phase}] = \text{Project Labor}[\text{phase}] * \text{Wage Rate}$$

The Wage Rate represents an average rate for all shipyard personnel. It includes their base salary and any benefits including medical, dental and retirement.

$$\text{Wage Rate} = 1600 \text{ dollars/person/week}$$

The overhead rate represents 33% of the direct charges on the project as reported by Ingalls on the DDG-51 program.

$$\text{Weekly Overhead Cost}[\text{phase}] = \text{Weekly Phase Labor Cost}[\text{phase}] * \text{Overhead Fraction}$$

*Weekly Costs[phase] = Weekly Phase Labor Cost[phase]+ Weekly Overhead Cost[phase]*

*Total Weekly Cost = SUM(Weekly Costs[phase!])*

The Total Cumulative Project Cost is the sum of all of the Phase Costs and any penalties for missing schedule milestones. The Overrun Charges are identified in the Build Strategy.

*Project Cost = SUM(Cumulative Phase Cost[phase!])+Overrun Charge*

*Overrun Charge = IF THEN ELSE(Project is Done,0,MAX(0,Overrun Charge Rate\*(Time-(10+ Initial Schedule Completion Time[ONBOARD]))))*

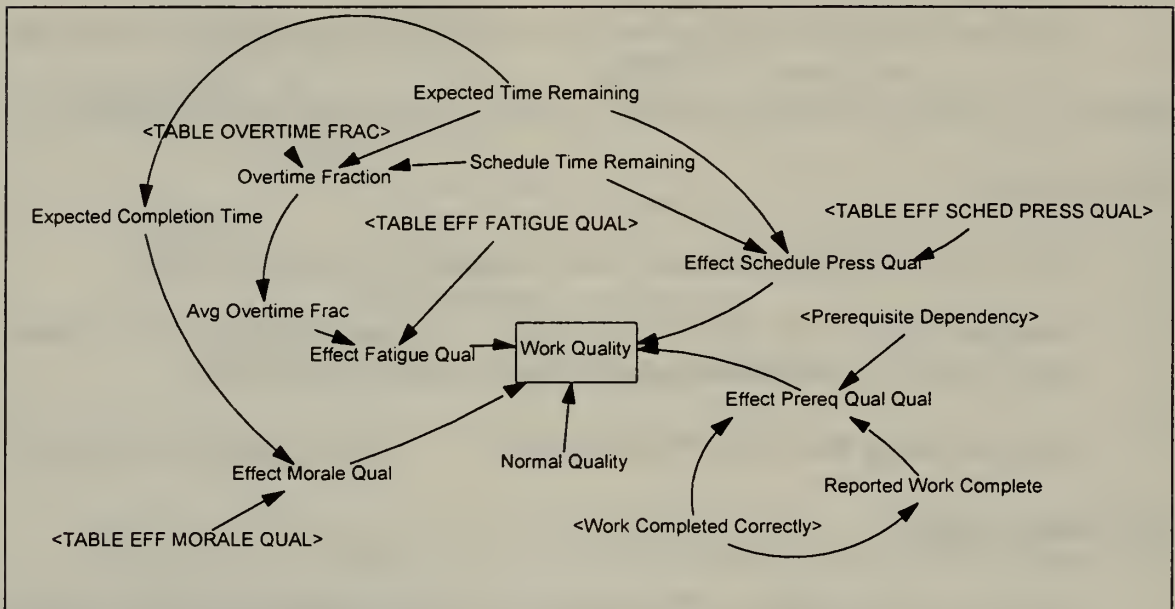
*Overrun Charge Rate = 350000 dollars/week*

#### **4.25 Quality Effects**

Quality is a critical factor in the operation of the Ship Production Model. A base quality is chosen for each shipyard. Improved quality requires an investment in the control of the project. Shipyards choose to manage quality in different ways. Japanese shipyards dedicate much effort to finding the root causes of quality problems in the process. This tends to increase the overall quality of the products coming through the yard. American yards tend to use rework to correct quality problems as needed. They do not generally trace the cause of each flaw back to its origin. The competitive nature of the commercial shipbuilding market force the Japanese to find problems and correct them. The Cost Plus Fixed Fee type contract associated with many Navy contracts does not promote perfect first time quality.

In this model, quality is defined as the amount of work done correctly. The quality of the work done in each phase determines how much rework is generated in the

process. Quality is affected by several factors including the quality of previous work, fatigue and stress. Figure 4-23 shows the relationships between variables in this sector.



**Figure 4-23 - Effects on Quality**

The Work Quality is determined by the cumulative impact of many effects. Normal Quality is degraded by an effect for morale, fatigue, schedule pressure and prerequisite quality. A formulation to allow some noise to the equation is included.

$$\text{Work Quality}[\text{phase}] = \text{Normal Quality}[\text{phase}] * \text{Effect Morale Qual}[\text{phase}] * \text{Effect Fatigue Qual}[\text{phase}] * \text{Effect Schedule Press Qual}[\text{phase}] * \text{PROD}(\text{Effect Prereq Qual Qual}[\text{phase}, \text{prereq!}]) * (1 - \text{RANDOM } 0 \text{ } 1()) * \text{QUALITY NOISE}$$

The effect of fatigue on quality is a function of the average overtime used. During the first few weeks overtime is used, no effect is felt on quality. As the use of overtime becomes chronic, quality begins to drop as the work force is tired.

$$\text{Effect Fatigue Qual}[\text{phase}] = \text{TABLE EFF FATIGUE QUAL}(\text{Avg Overtime Frac}[\text{phase}])$$

$$\text{Avg Overtime Frac}[\text{phase}] = \text{INTEG}((\text{Overtime Fraction}[\text{phase}] - \text{Avg Overtime Frac}[\text{phase}]) / \text{Time to Average Overtime}, 1)$$

The effect of morale on quality is a function of how well the project is performing. If the project proceeds on schedule with few problems, no effect is perceived. When the project starts to experience difficulties, the morale of the workforce drops. Performance based goals which may lead to added incentives are not reached.

*Effect Morale Qual[phase] = TABLE EFF MORALE QUAL((Expected Completion Time[phase] - Initial Schedule Completion Time[phase])/Initial Phase Length[phase])*

Next is the effect of prerequisite quality on quality. If the quality of the upstream phases is high, the following phases have higher quality. If the design is poorly done, all the work that follows will experience quality problems.

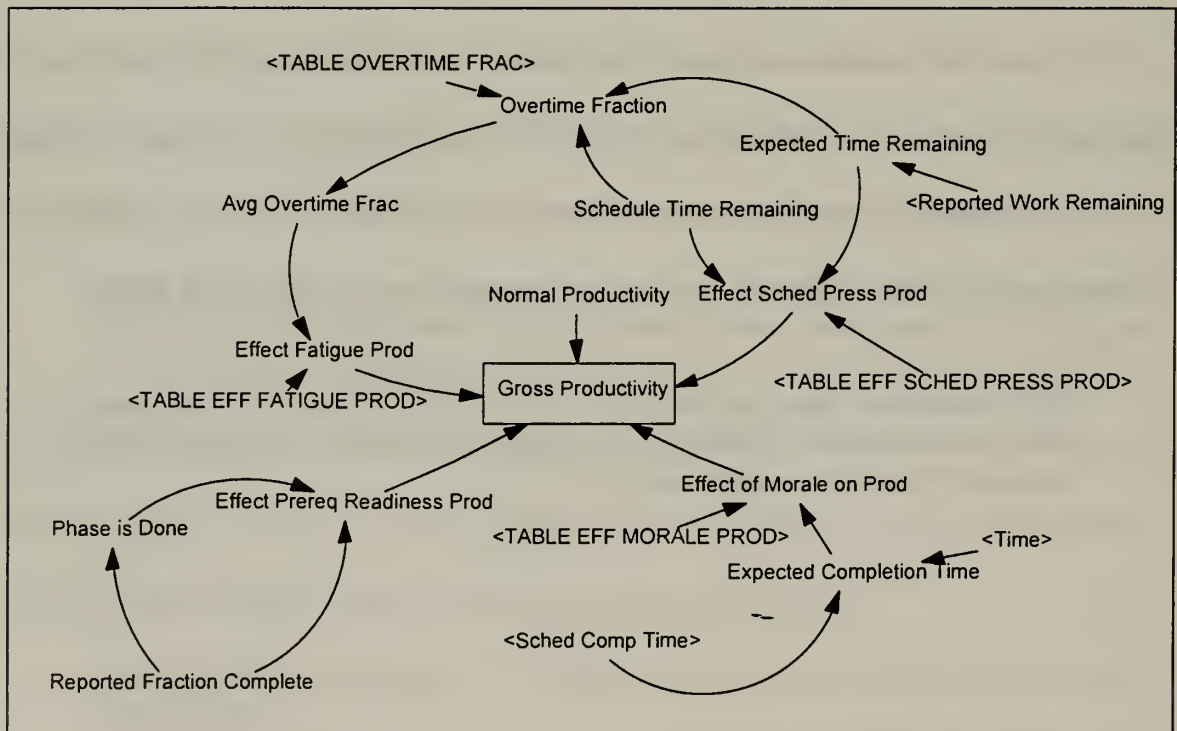
*Effect Prereq Qual Qual[phase,prereq] = IF THEN ELSE(Prerequisite Dependency[phase,prereq], XIDZ(Work Completed Correctly[prereq],Reported Work Complete[prereq],1),1)*

The effect of schedule pressure on quality represents management pressure to complete the project. This pressure at first increases quality as increased manager oversight focuses the workers on the task at hand. As Schedule Pressure progresses over a longer period of time, the stress of meeting a deadline starts to degrade the quality.

*Effect Schedule Press Qual[phase] = IF THEN ELSE(Phase is Active[phase], TABLE EFF SCHED PRESS QUAL(XIDZ(Expected Time Remaining[phase], Schedule Time Remaining[phase],5)),1)*

## 4.26 Productivity Effects

The productivity on the project is another important variable. It is used to determine the rate of work that is possible by the workforce. It is effected by many of the same dynamics as quality. Productivity has been the weakness of American shipyards for many years. Studies conducted in the late 1960's identified many of the same problems we are experiencing with productivity today.<sup>57</sup> Why has it taken more than 30 years for US shipyards to try to improve the productivity of their workforce? These studies measure productivity but do not measure quality. These two should both be measured as quality has a major impact on productivity. To compete with the foreign yards on commercial contracts, productivity and quality improvements are critical. No amount of subsidy in the world can take the place of a highly trained, productive and motivated work force.



<sup>57</sup> Beazer, W.F., Cox, W.A., and Harvey, C.A., (1972), "US Shipbuilding in the 1970's," Lexington Books, Lexington MA

## Figure 4-24 - Effects on Productivity

The Gross Productivity is the amount of work that people can get done in a week. It is the result from the cumulative effects of morale, fatigue, schedule pressure, and the completeness of the previous phase. Gross Productivity is difficult to measure on a daily basis in the shipyard.

*Gross Productivity[phase] = Normal Productivity[phase] \*Effect of Morale on Prod[phase] \* Effect Fatigue Prod[phase] \*Effect Sched Press Prod[phase] \* PROD(Effect Prereq Readiness Prod[phase,prereq!])*

*Effect Fatigue Prod[phase] = TABLE EFF FATIGUE PROD(Avg Overtime Frac[phase])*

*Effect of Morale on Prod[phase] = TABLE EFF MORALE PROD((Expected Completion Time[phase]- Initial Schedule Completion Time[phase])/Initial Phase Length[phase])*

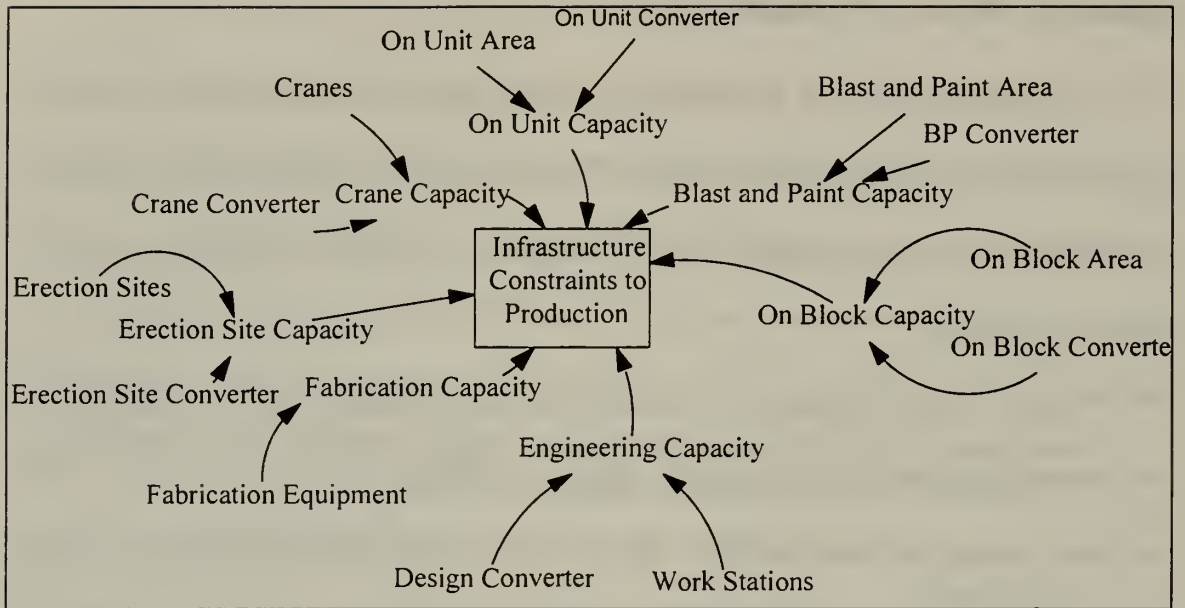
*Effect Prereq Readiness Prod[phase,prereq] = IF THEN ELSE(Prerequisite Dependency[phase,prereq],IF THEN ELSE(Phase is Done[prereq],1,PREREQ EFF SPEED LOOKUP(Reported Fraction Complete[phase])),1)*

*Effect Sched Press Prod[phase] = TABLE EFF SCHED PRESS PROD(MIN(5, XIDZ(Expected Time Remaining[phase],Schedule Time Remaining[phase],5)))*

*PRODUCTIVITY NOISE = 0*

### 4.27 Shipyard Constraints

The constraints to production in the shipyard are a function of the installed equipment. Every shipyard visited had concerns about what the limiting factor was for increasing their throughput. The constraints listed below in Figure 4-25 represent structures that are constraints in all shipyards. The values for the constraints at several of the yards visited are included in Chapter 3. The specific constraints in the equations below represent two shipbuilding positions at Ingalls Shipbuilding.



**Figure 4-25 - Constraints to Production**

The constraints modeled include:

*Blast and Paint Area = 8 Blocks/week*  
*Cranes = 500 lifts/week*  
*Work Stations = 100 drawing/week*  
*Fabrication Equipment = 900 work order/week*  
*On Block Area = 30 Blocks/week*  
*On Unit Area = 100 products/week*  
*Erection Sites = 30 Blocks/week*

Each constraint is converted to determine how many work orders per week it can support. For the Design Phase the only constraint Engineering Work Stations. For Fabrication it is Fabrication Capacity which represent the number of burn tables, bending and rolling machines in the yard. On Unit Capacity is the amount of covered space set aside for assembly of units. The On Block phase can be constrained by space for bringing units in contact with structural steel and Blast and Paint capacity. On Board can be constrained by the number of Erection Sites available and Crane Capacity.

*Infrastructure Constraints to Production[DESIGN] = Engineering Capacity*

*Infrastructure Constraints to Production[FABRICATION] = Fabrication Capacity*  
*Infrastructure Constraints to Production[ONUNIT] = On Unit Capacity*  
*Infrastructure Constraints to Production[ONBLOCK] = MIN(On Block Capacity, Blast and Paint Capacity)*  
*Infrastructure Constraints to Production[ONBOARD] = MIN(Crane Capacity, Erection Site Capacity)*

For Ingalls the constraint to production is the number of burn tables available in the fabrication area. Plans for this facility include a complete renovation once sufficient work merits the upgrade. The entire set of equations used in the Ship Production Model can be found in Appendix B.

### **4.3 Base Model Run**

With the key sectors and equations in the Ship Production Model identified we can examine a base run of the ship construction process. In this section the parameters for the SOCV identified in the Build Strategy are used to determine the cost, schedule and quality of the project at Ingalls. The base case is used for comparing dynamic hypotheses concerning the project performance at the end of this chapter and for comparisons with another shipyard in the next chapter. Several policy decisions are examined including the effect of quality, optimum manning levels and the use of overtime.

#### **4.31 Model Behavior - Base Case**

The base case behavior is shown in the figures below. The graphs for Total Project Costs and Phase Costs, Project Labor by phase, Work Quality and Undiscovered Rework are included. The Project Completion time is approximately 128 weeks.

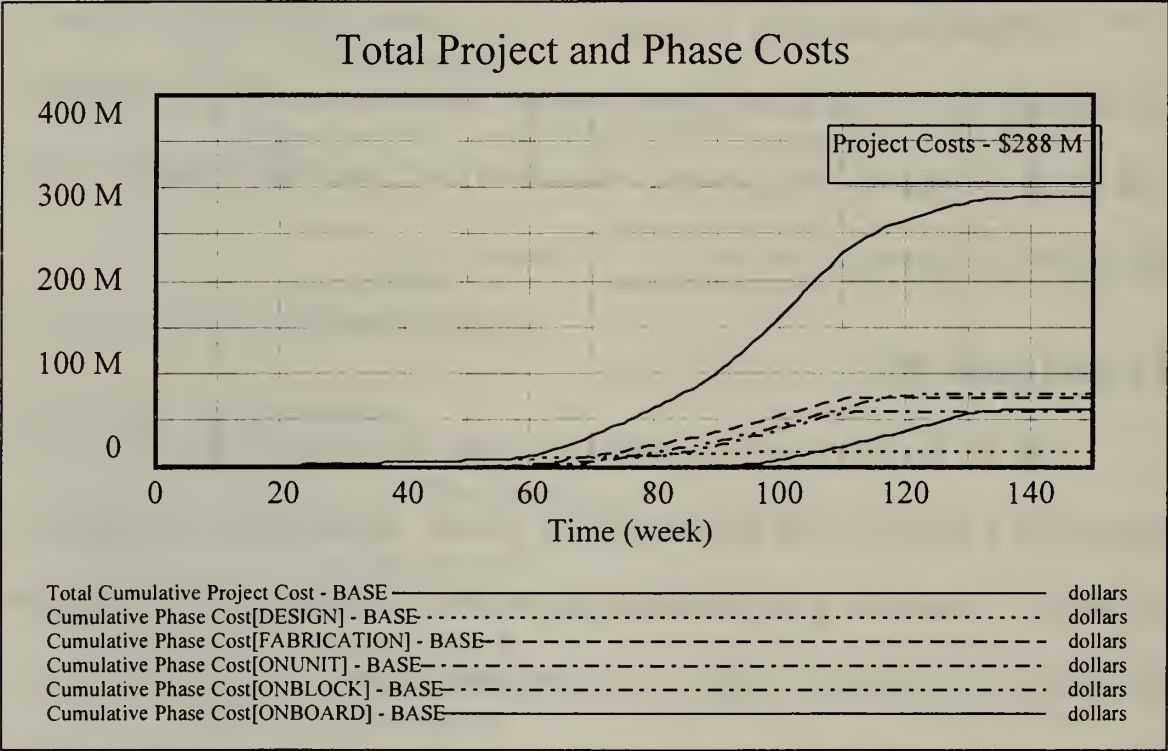


Figure 4-26 - Base Run Costs

The cumulative costs of each phase are shown in Figure 4-27 with a finer scale to determine what costs are associated with each phase.

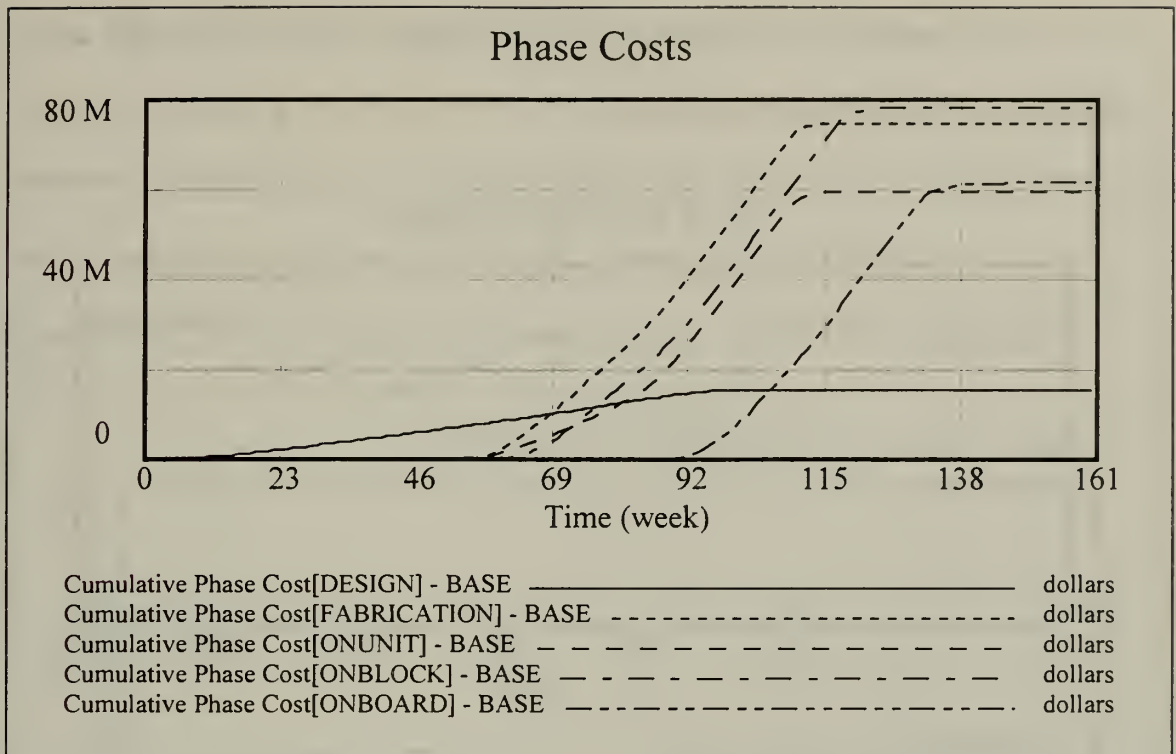


Figure 4-27 - Base Run Phase Costs

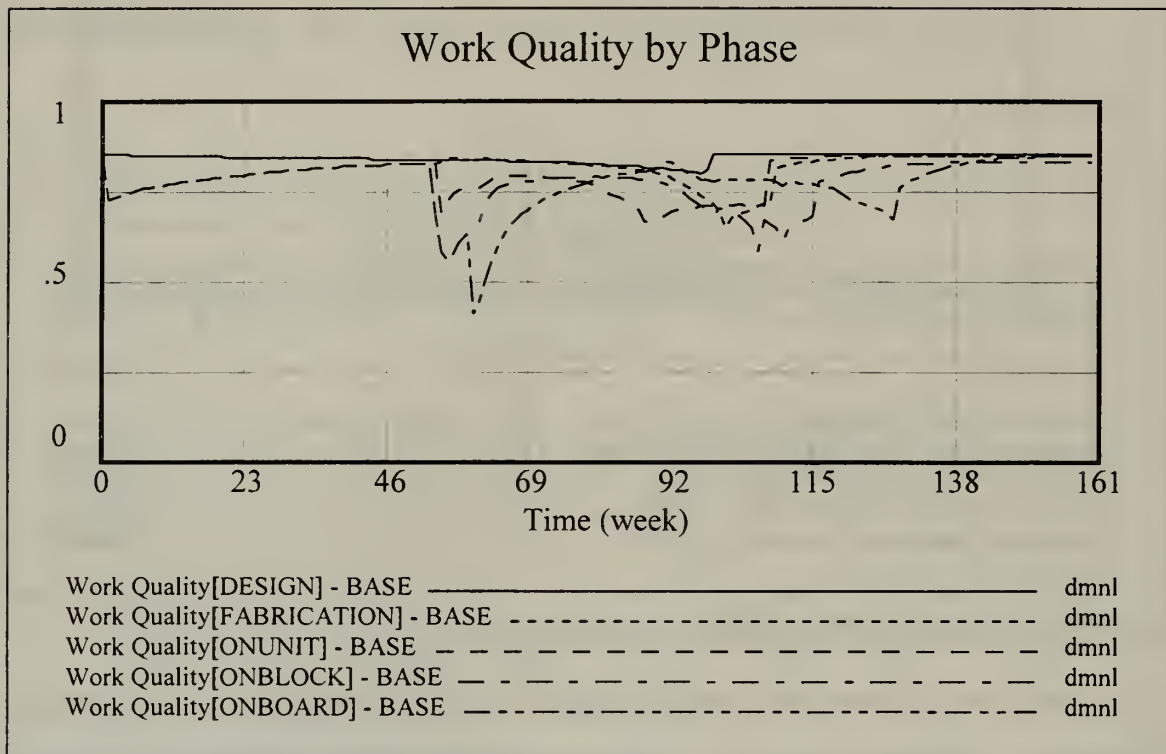
On Block Construction ends up being the most expensive phase followed by Fabrication. Although more work orders are completed in Fabrication, the Gross Productivity of this phase is higher. A breakdown of the percentage of the project costs and the project initial work definition is included in Table 4 -16.

Phase	Work Packages	Percent of Work	Cost (\$M)	Percent of Cost
Design	12500	10.95%	15.54	5.38%
Fabrication	39726	34.79%	74.41	25.76%
On Unit	14123	12.37%	59.43	20.58%
On Block	26300	23.03%	78.04	27.02%
On Board	21530	18.86%	61.39	21.26%
Over Run Charges	0	-	0	-
Total	114179	100%	288.81	100%

Table 4 -16 - Cost Percentage by Phase

The reason for the difference between the percent of work and the percent of cost in each phase is the productivity.

The next measure to determine project performance is quality. The work quality for the base run is represented in Figure 4-26.



**Figure 4-28 - Base Run Work Quality by Phase**

The quality on the project is above 75% for most of the project. Some problems occur in the beginning of each phase due to rework discovery from the previous phase. On Board in particular takes a large dip in quality and then recovers. The problems with quality lead to some problems with Rework in some phases as shown in Figure 4-29.

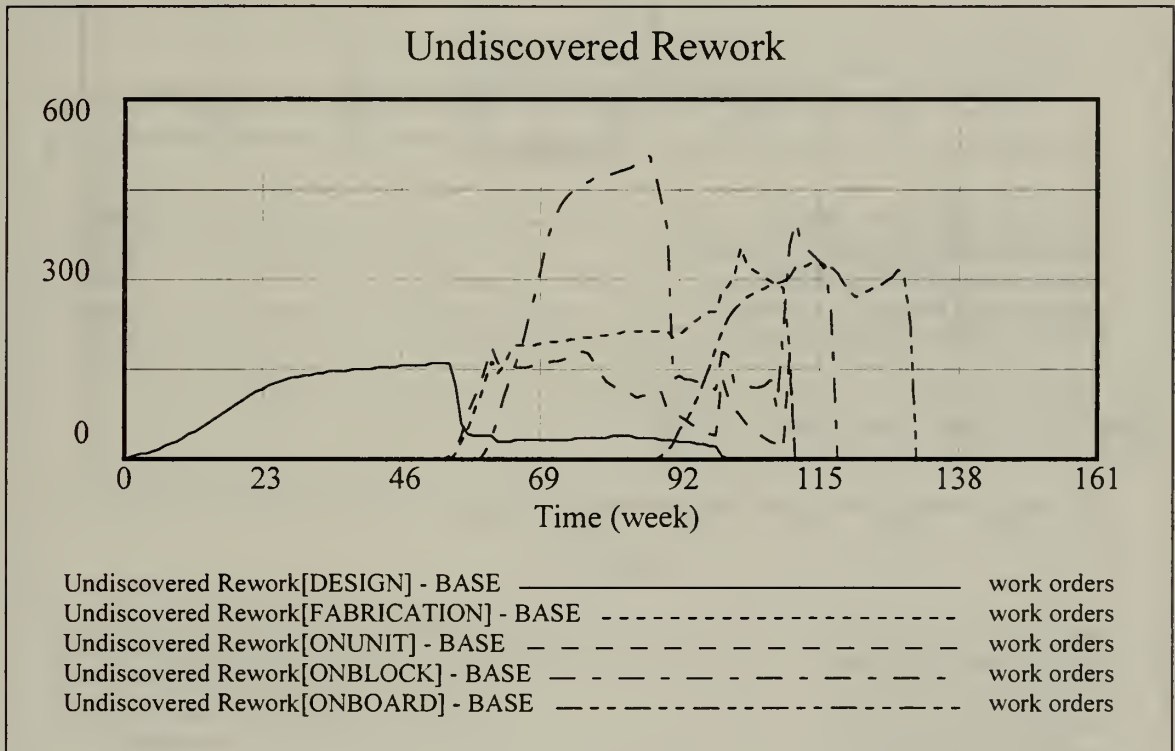


Figure 4-29 - Base Undiscovered Rework

The project labor for the base case is shown in Figure 4-30. Manning reaches the constraint of 850 people in each phase after design. It may be more cost effective to raise the cap on manning to allow more people to work on the project when needed. The impact of raising or lowering the manning cap will be discussed in more detail in the next section.

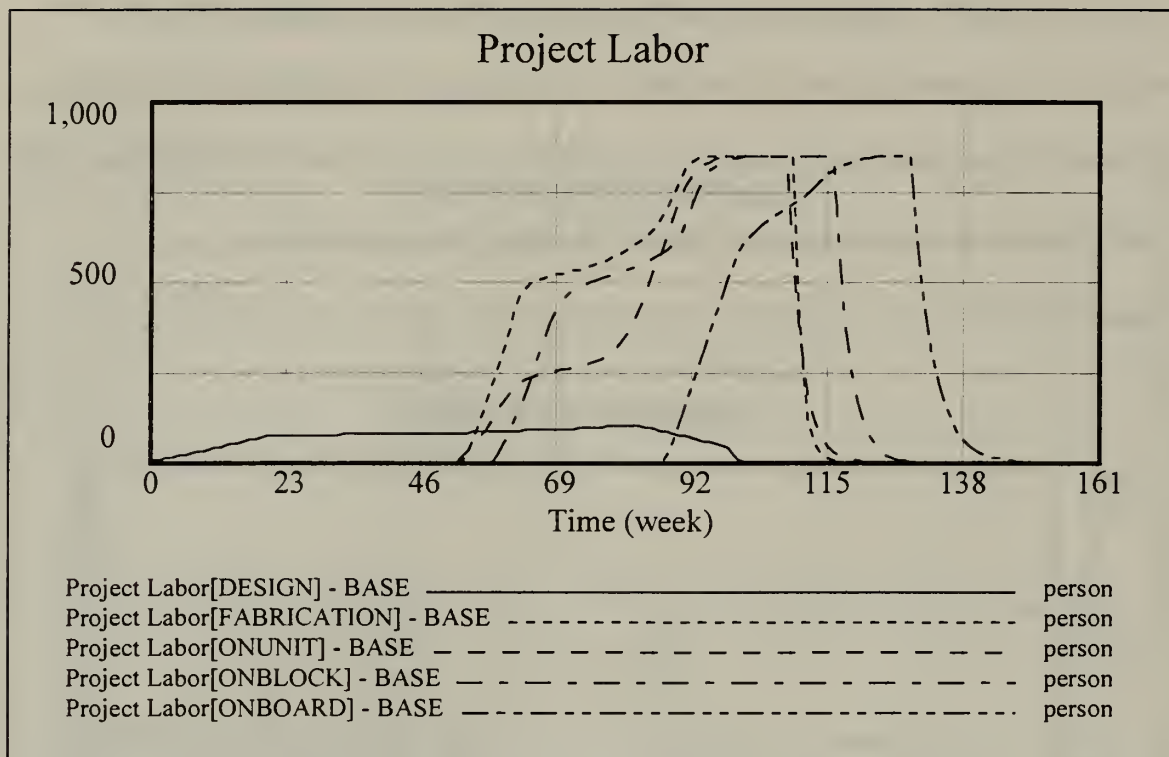


Figure 4-30 - Base Case Labor by Phase

One of the most interesting features of the Vensim software is the ability to do causal tracing. Finding the root cause of quality or productivity problems is something every production planner at the shipyard would like to be able to do quickly. Using causal tracing the problems in productivity in each phase can be examined. As shown in Figure 4-31, a problem in productivity in the On Unit phase.

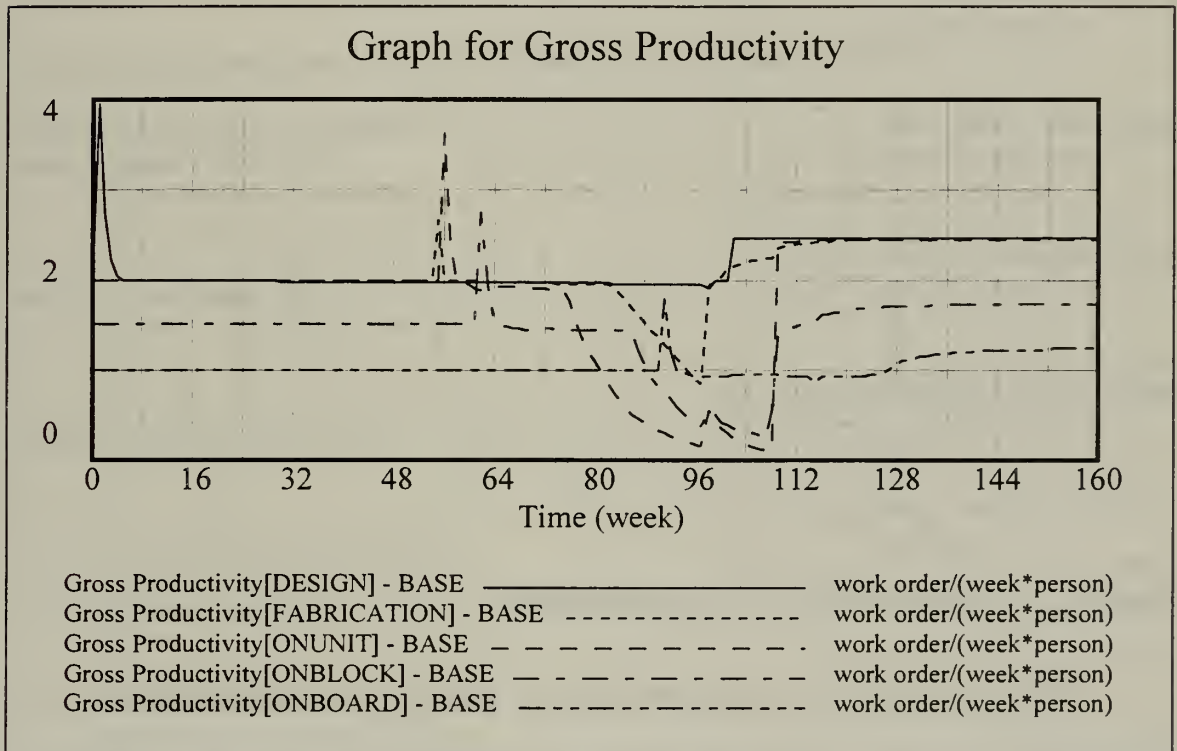


Figure 4-31 - Productivity of Phases

To determine the root causes of this loss in productivity, a closer look is taken at the factors effecting this phase. The results are shown in Figure 4-32.

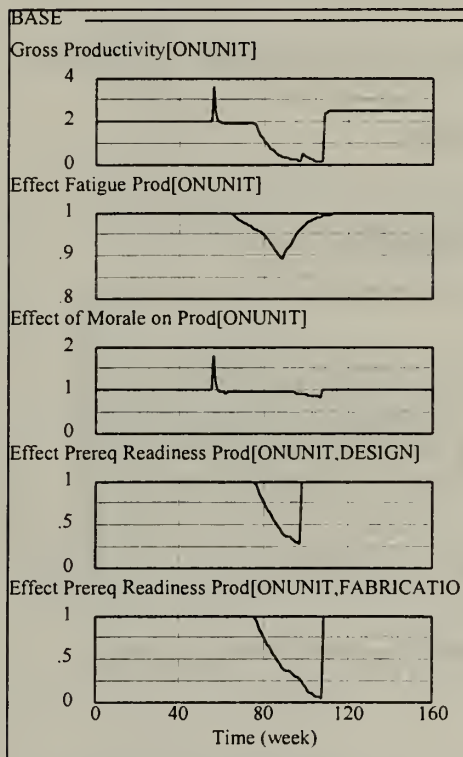


Figure 4-32 - Factors Effecting On Unit Productivity

The primary factor effecting the productivity in the On Unit phase is a lack of prerequisite readiness from the Fabrication Phase. Additionally, the Design Phase is effecting On Unit work.

Although the real problem is occurring in Fabrication and Design, the loss of productivity does not show up until the small parts are assembled in the On Units phase. The Fabrication productivity and the causes effecting it are included in Figure 4-33. A combination of factors effects Fabrication productivity. Fatigue contributes to the degradation indicating excess use of overtime. Additionally, the availability of drawings from the design stage have an effect on productivity in Fabrication.

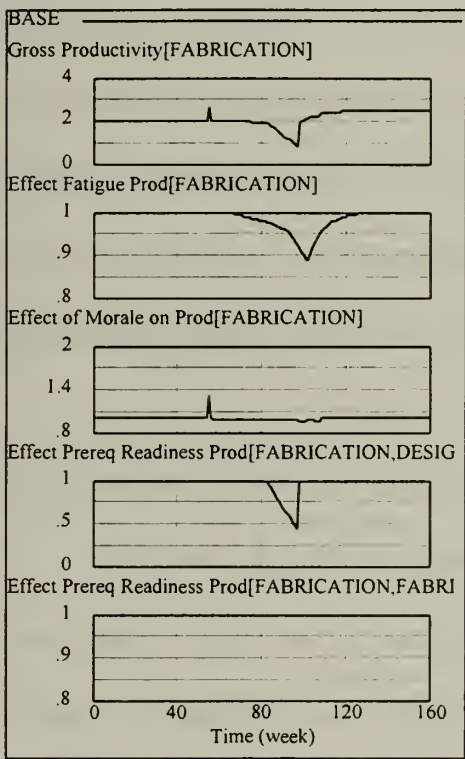


Figure 4-33 - Effects on Fabrication Productivity

This productivity degradation is magnified in the On Unit phase by design problems and fatigue. This behavior is typical in many yards. The interesting point is that the root causes of the problem can be found using a model of the process. Production planners spend countless hours in the shipyard trying to determine what can be traced in a

few minutes. If the model is calibrated to actual data in the yard, valuable insights could be found that are not intuitively obvious to shipyard managers. Corrective measures could then be taken to improve the conditions at the phase that is causing the root problem. In this case, the labor may need to be increased in Design and On Unit construction. A cost trade off can be conducted between sticking with the base case and adding labor to keep the process moving smoothly. Adding people to the project may run into training and quality problems. Issues like these will be discussed in the next section.

#### **4.4 Policy Investigation on SOCV Project**

In this section several of the policies identified in the Build Strategy to control the project costs are examined. The base run provides a benchmark with which to compare our policy analyses. The policies that are investigated include:

- Project Quality
- Use of Overtime
- Maximum Manning Levels

These issues are all part of the shipyard production planning process prior to the start of the construction sequence. In most cases the policies used are chosen from successful projects. No two projects are exactly the same. Being able to rapidly analyze these issues using simulation has generated great interest at several yards. Being able to test drive a policy through the entire construction cycle is a valuable tool.

##### **4.41 Effect of Quality on Project Performance**

The level of quality in a product is a strategic decision every manufacturing firm must make. In the past, it was generally thought that high quality meant high costs. Japanese car manufactures, especially Toyota, proved that quality could be built into the product. As quality increases, rework is reduced and the cost of building the product decreases.<sup>58</sup> Most of the US shipyards do not have the same commitment to quality that the Japanese shipyards exhibit. For the US yards, increasing quality has a significant

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<sup>58</sup> Womack, J.P., Jones, D.T., and Roos, D., (1990) "The Machine That Changed the World", Rawson Associates, New York, NY.

cost. Instead of finding the root causes of low quality, they choose to correct it with rework. This tends to increase the total hours they can charge to any particular contract.

When asked, the shipyards are not willing to discuss the quality in their yard or do not understand the impact of first time quality. Quality is not an attribute that is easily quantifiable. Quality, for this paper is defined in context with rework. Products that do not require rework have sufficient quality to continue in the process. This does not mean that they are perfect, just that they pass the Quality Assurance for that level. The better the quality on any small component, the easier it is to assemble down the line. BIW estimates that they have about 3% rework on their ships. Ingalls, like a true competitor, estimated they had 2.5% rework. Neither one of these representations is realistic. The grinding, cutting and shipfitting required to bring the ship together because the parts don't fit is rework. Ingalls and Bath both seem to have internalized these modifications to the assemblies as part of doing business. Based on my observations, perfect first time quality is not being sought in US shipyards.

The closest to a realistic discussion of shipyard quality occurred at NASSCO where it was estimated that between 20 and 25% of all fabricated parts required some sort of rework. This level is more along the lines of what other industries are tracking for quality and rework. Striving for perfection is a lofty goal. The Japanese are much further down the line than American companies in this area. US yards do not yet grasp the fact that increasing the quality of the product can decrease overall costs.

For the first policy analysis, three levels of quality are investigated. The best possible situation with 100% quality is simulated to show what we could possibly achieve. This run represents the project every manager dreams about. It is also the representation project planners get from static models like CPM or PERT. These packages are not very effective once the project has started and rework or other problems are experienced on the project. They cannot capture the feedback between phases and the non linear effects experienced in shipbuilding. The base quality at Ingalls is set at 85%. This is high based on some of the benchmarking studies conducted in other manufacturing industries.<sup>59</sup> These studies were conducted on companies that had quality problems. Finally a lower value of quality, 65% is simulated which is close to the level described as problematic. The impact each of these values has on the total cost of the project is shown in Figure 4-34.

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<sup>59</sup> Cooper, K. G. March 1993. The Rework Cycle: Benchmarks for the Project Manager. *Project Management Journal*. pp. 181-186.

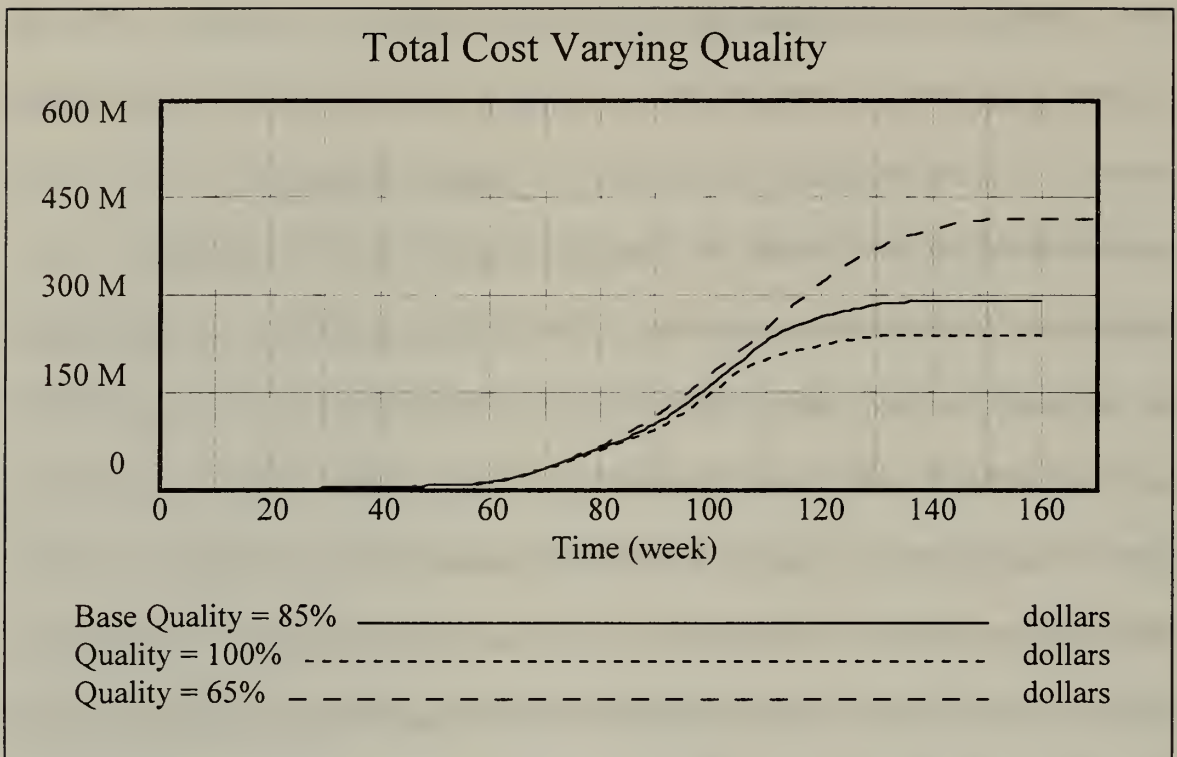


Figure 4-34 - Effect of Quality on Cost

The difference in end cost is dramatic. The cost of the project more than doubles when the quality drops from perfect to 65%. Clearly improving the quality of the products will help at each subsequent phase of production. As quality decreases, the amount of rework required increases. More work to do forces the assigned labor to work harder. This leads to additional problems with productivity as the effects of fatigue and schedule pressure come into play. The result is a project that is delivered later at much higher costs.

The yard that had the highest quality for its final products, BIW, did not understand that quality should not be a function of repetitive rework. At BIW, the quality efforts were being concentrated in the On Block area. By this time the prerequisite

quality of Fabrication and On Unit have determined the inherent quality of the ship. Only using extreme measures in the ship fitting effort can the quality be brought to a higher level at significant cost to the customer. The same dynamic took place on high performance German automobiles. The quality of the product was not high. The effort to make them better quality after line production added tens of thousands of dollars to the sticker price of the car.<sup>60</sup> Understanding where the emphasis of the management effort needs to be placed is difficult. Most managers focus on where the most man hours are being expended. At Bath this was in On Block Construction in PO1 and PO2. The critical place to look for quality is in the early stages of Fabrication and On Unit Construction. Bath has started to make improvements in this area which is encouraging.

#### **4.42 Manning Levels**

Properly planning the staffing levels on a ship project and in the yard is a very difficult problem. If too many people are assigned to a ship, they tend to get in one another's way. If too few people are assigned, they get fatigued as the Schedule Pressure and Overtime hours build up. Ingalls has determined through trial, error and simulation with their Strategic model that a maximum of 850 people works well for them on DDG-51. For the SOCV, the value of 850 people for each phase after design was also used as the cap. Other yards are still not sure what number is most efficient.

A policy analysis is conducted to determine if the 850 is the optimum level for maximum labor on the SOCV project. Three cases are examined. The first is the base

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<sup>60</sup> Womack, J.P., and Jones, D.T., (1996) "Lean Thinking", Simon and Schuster, New York NY.

case using Ingalls value for maximum labor on DDG-51. As was seen in the last section, this cap resulted in a 128 week project with no over run charges. The level is increased to the old labor cap at Ingalls, 1200 people. Finally the cap is reduced to 400 people to see what the impact of a minimum staffed project would be. The scheduled completion times for each phase are left the same. The results of the variations in staffing are depicted in Figure 4-35.

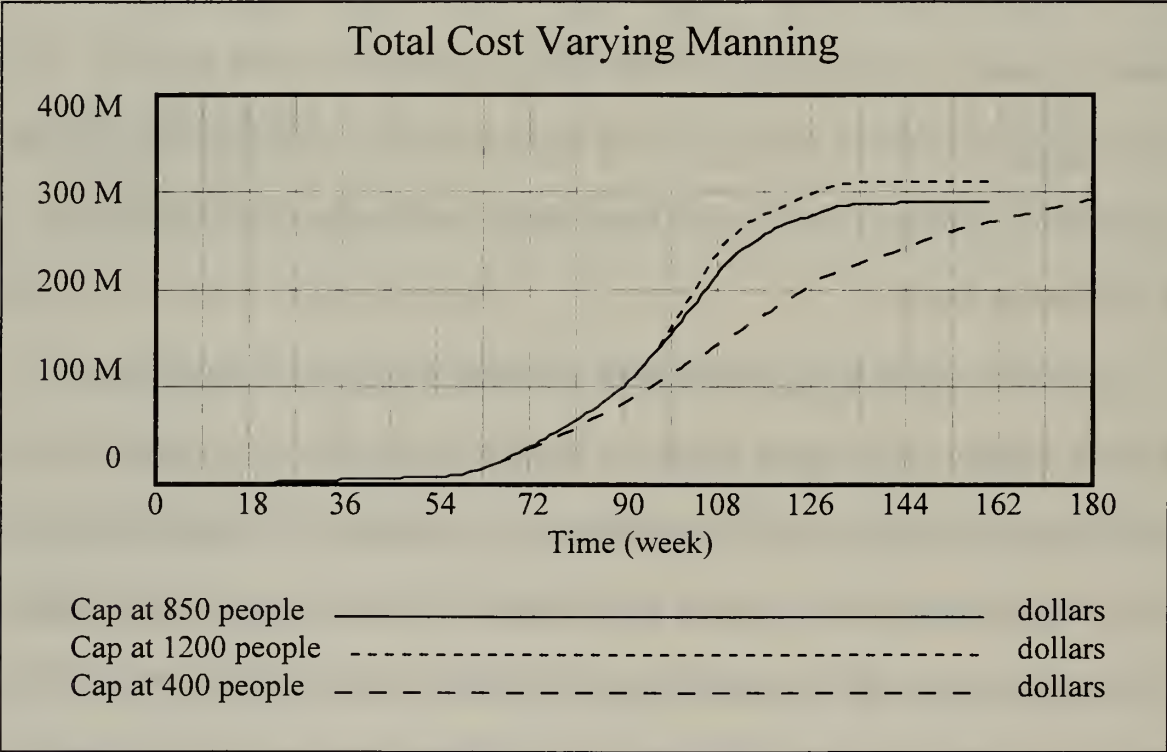


Figure 4-35 - Maximum Project Labor

With increased staffing the project finishes slightly earlier but with an increase in cost of over \$25 million. The minimum staffing case results in a longer schedule. As the project pushes beyond the prescribed limits, over run charges add up. Schedule pressure and fatigue degrade productivity. The project is eventually terminated behind schedule and over budget at around 200 weeks.

Overall shipyard manning is another area of strategic interest. Manning levels fluctuate with the amount of work the shipyard has on the order book. This problem will be discussed in more detail Chapter 5 as an area of future investigation with the Ship Production Model.

#### **4.43 Overtime Policy**

The final policy examined is the use of overtime on the project. Overtime can be used to effectively smooth out the peaks and valleys in manning levels as the project progresses. The Build Strategy identified several weeks toward the middle of the project where more blocks than usual were being erected. In the short run, increasing overtime tends to motivate the workforce. Overall productivity goes up as the workers see more money coming home in their pay checks. As the use of overtime continues, however, this trend reverses itself. As workers become fatigued, the productivity and quality of their work dropped off. This tends to put the project further behind schedule. It may also trigger the use of still more overtime which may exacerbate the problem.

Three cases are simulated. The base case uses overtime moderately. The project must be several weeks behind schedule before overtime is authorized. The slope of the table function is gradual and peaks at around 1.5 times the normal work week. The second case uses overtime as soon as a problem occurs, the peak overtime is double the normal work week. The final case is for no overtime. All policies were observed at some

point in the shipyard visits. Determining which policy is the most efficient is of great interest to the yards.

The results of the different uses of overtime are shown in Figure 4-36.

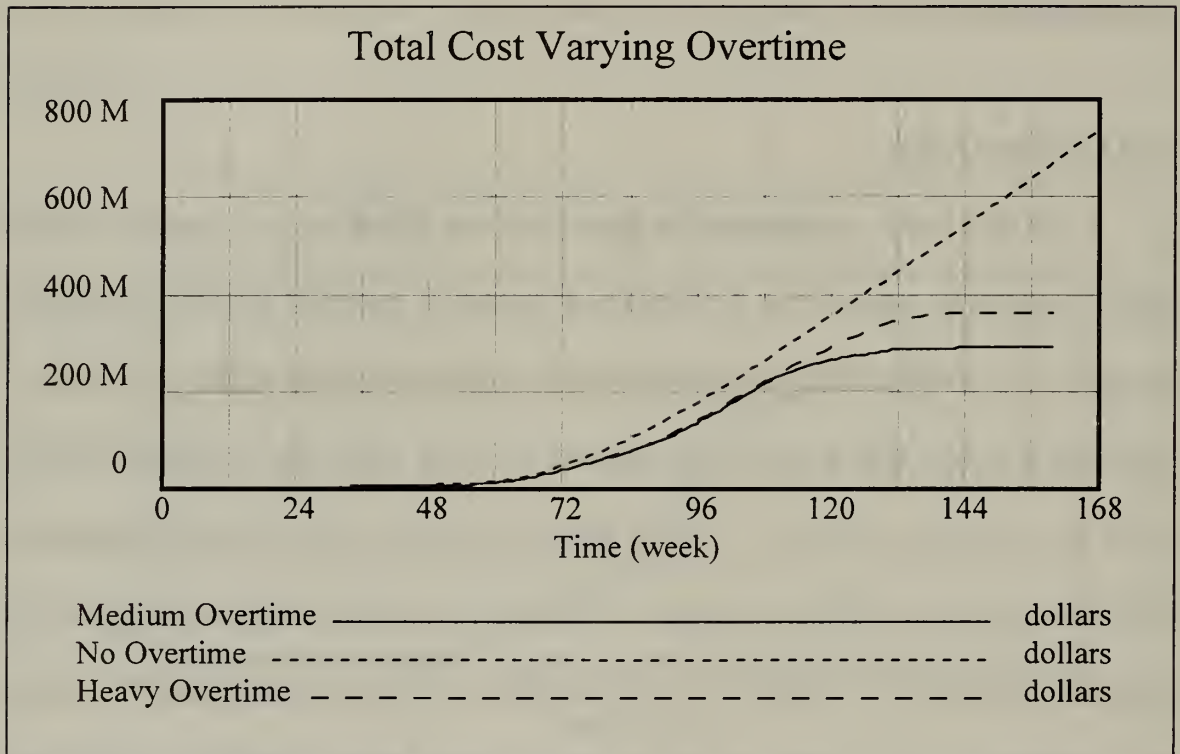


Figure 4-36 - Cost of Varying Overtime

The case of heavy overtime results in longer completion time and higher end costs. This is counterintuitive. A look at the Gross Productivity for each phase in which heavy overtime is used in Figure 4-37 provides some answers. As the labor is forced to work longer hours, fatigue starts to reduce productivity. This trend is gradual at first but drives productivity to lower values in later stages.

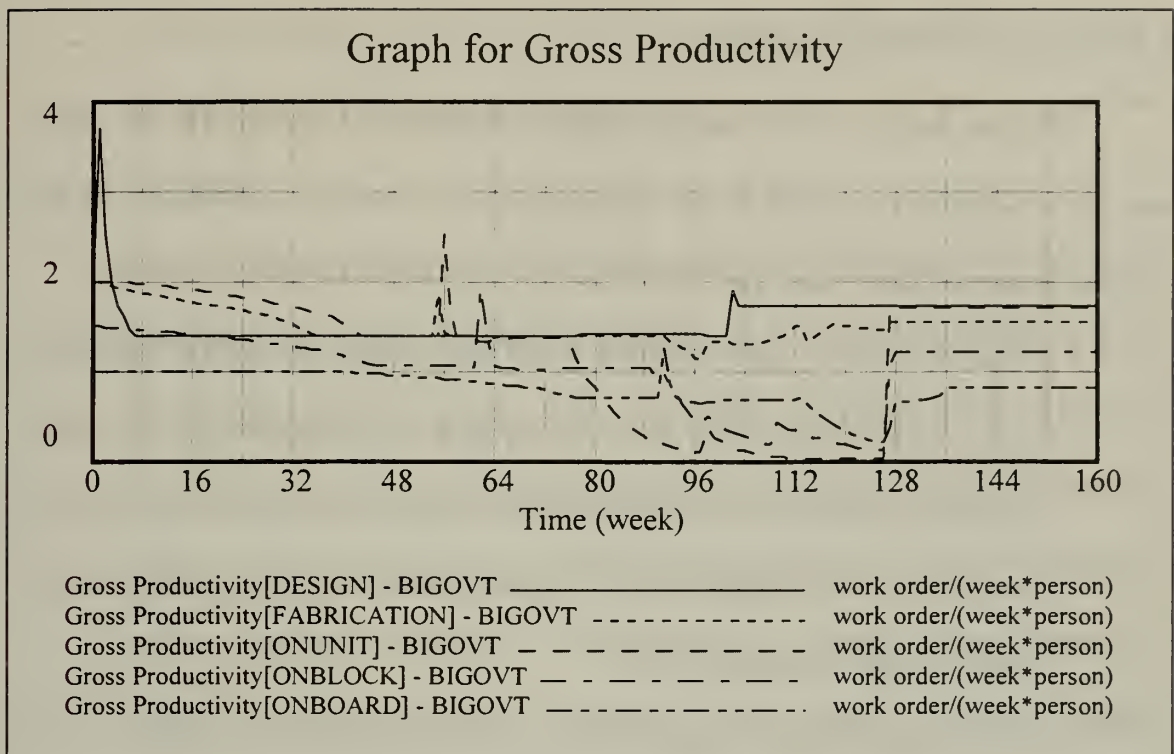


Figure 4-37 - Effect on Productivity of Overtime Policies

The case in which no overtime is used is similar to the minimum staffing result. The project falls behind schedule and cannot recover. The costs continue to grow linearly as the penalties for schedule over runs accumulate. Hiring new people is delayed by the requirement that they be trained. The project is eventually canceled.

The base case seems to provide the best compromise between too much overtime and too little. The shape of the table function which describes the overtime policy is adequate for this level of analysis. Use of overtime is an effective tool if it is controlled.

#### **4.4 Summary of Policy Analysis**

The base case of SOCV through Ingalls establishes the benchmarks for further analysis in Chapter 6. Based on the quick analysis of quality, manning levels and overtime using the Ship Production Model, the following actions are recommended:

- Work to achieve higher qualities in the early stages on Design, Fabrication and On Unit Construction. If the small pieces are of high quality, they enable the larger assemblies to fit together. If the larger assemblies do not need to be bent or cut to fit together, there is a better chance that when it comes time to erect the ship, the pieces will fit.
- When a quality problem does occur, trace the problem to its root cause, even if it means disrupting the entire flow of material for a period of time. This prevents unnecessary rework in later stages. The benefits of finding the root causes in the process are much greater than correcting a problem with iteration at the end of the assembly line.
- The maximum manning level of 850 works well with the current schedule. In order to shrink the cycle time, more labor will need to be applied. This could lead to additional coordination problems. Further refinement of the optimal manning on the project should be conducted using real productivity data.
- Use overtime moderately and not for more than a few weeks at a time. It is an effective tool to increase the work intensity of the labor. If used chronically it will cause problems with quality and productivity which will further delay the project.

- The current shape of the overtime table function in the Ship Production Model is sufficient. Calibrating with actual data would be the next step in the process.
- It is critical to remember that actions taken to correct one problem may adversely effect another situation. Feedback is an important concept to keep in the back of any managers head. The entire system must be taken into consideration. Using an interactive model like the Ship Production Model can help to teach managers not to discount other areas in the yard where their policies may cause problems. For example, using overtime in the Fabrication phase may help to meet the deadline for that phase. However, quality problems from Fabrication may cause all the subsequent phases to experience productivity problems. The real costs of working overtime in Fabrication will not be felt until the rest of the ship comes together. In some circumstances the overall effect of a policy may push costs higher on the ship project instead of the desired reduction in cost.

## Chapter 5 - SOCV Case Studies - BIW vs Ingalls

One of the basic premises in System Dynamics is that most of the problems management experiences are a result of endogenous factors to the system and not exogenous shocks. Deming stated, “...workers performance is determined solely by the system in which they are working. Management must not only recognize that most of the failure for a system to produce the desired results is due to the system itself, but that management must change itself, and the system, to improve the outcome.”<sup>61</sup> If one believes most problems are internally generated, many of the solutions to management problems are within reach.

All of the shipyards visited experience difficulties dealing with the complexities of the shipbuilding process. Some have a better understanding of the dynamics than others. All yards are able to describe feedback but have trouble quantifying its impact. Ingalls has an easier time than the other yards as they have used system dynamics project models for over 15 years to manage their internal production processes. Even Ingalls would like to improve their model to capture more things in real time and to investigate issues at a lower level of aggregation. All yards found value in being able to better predict the costs and benefits of these issues using simulation. Shipyard managers are able to describe the different facets of the process individually but could not address the system as a whole.

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<sup>61</sup> Rack, F.H., (1995) Increasing U.S. Shipbuilding Profitability and Competitiveness, Ship Production Symposium, The Society of Naval Architects and Marine Engineer.

System Dynamics project models have been very effective in capturing issues like feedback and internal dependencies associated with large projects. A systems perspective is valuable to any manager on any large project. *“The System Dynamics perspective is the single most valuable tool I have experienced in my 30 years in ship construction management.”*<sup>62</sup> The true impact of management decisions cannot be fully evaluated without the “big picture.”

Ingalls and BIW, the two producers of DDG-51, will be compared qualitatively to determine why Ingalls out performs BIW for cost on DDG-51 contracts. This comparison provides the framework of several topics of interest. The Key Events Schedules are examined. Suggestions from personnel at both yards about why the cost difference occurs are included. Finally, the performance on the SOCV project at both yards will be modeled to determine if the difference in the process can be simulated using the Ship Production Model at its current level of complexity.

Several issues concerning the management of the SOCV program will be investigated using the Ship Production Model. Both Ingalls and BIW have expressed specific interest in quantifying changes to the way they build ships. The issues include:

- Level of Advanced Outfitting
- Shipyard Constraints

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<sup>62</sup> Goldbach, Richard, (1996) President and CEO of Metro Machine, Personal Communication

- Quantifying Benefits of Investment in Infrastructure

Ingalls is interested in determining the impact of increasing the level of pre-outfitting on the ships it builds. BIW is interested in quantifying the impact of investing in infrastructure to ease choke points in the shipyard.

Finally, other issues the Ship Production Model could be modified to support are discussed. There is great potential for a tool that can quickly analyze management policies and provide an indication of the behavior these policies generate.

### **5.1 Ingalls vs. BIW on DDG-51**

Ingalls has consistently provided better cost performance to the Navy on the DDG-51 program. According to publicly released information outlined in 5-1 , the average value for the difference between BIW and Ingalls is around \$10 million per ship. Some sources closer to the program estimate the difference to be between 500,000-750,000 man hours per ship and along the lines of \$20 million per ship.

Construction Costs	BIW	Ingalls
Total DDG-51 Built	12	10
Total Costs (Millions)	\$2891.7	\$2304
Average Costs (Millions)	\$240.975	\$230.4

Table 5-1 Comparison of DDG-51 Costs<sup>63</sup>

#### **5.11 - Key Events Schedule**

<sup>63</sup> Colton and Company (<http://www.coltoncompany.com/index.htm>)

In order to quantify the differences in the processes used at each yard a schedule of events for both yards is included in Tables 5-2 and 5-3.

BIW Key Events Schedule	Months Before Delivery
Contract Award	55
Start Cutting Steel	36
Start Fabrication	33.5
Start Pre Outfit	31
Lay Keel	21.5
Complete Machinery Loadout	19
Complete Final Sighting	16.5
Complete Hull Assembly	15
Complete Combat Systems Loadout	13
Complete Tank Painting	12
Launch	12
Complete Pull Main Cables	11.5
Complete Combat/AEGIS Weapon System Loadout	9
Complete Main Machinery Alignment	7
Load Fuel Oil for SSTG Activation	6.5
Light Off AEGIS System	6.5
Light Off SSTG	6
Battery Alignment	6
Spin Main Engines	5
Compartment Air Tests	4
Dock Trials	4
Transit to Portland for dry-docking	3.5
Dock Ship	3.5
Undock Ship	3
Compartment Inspection	3
Transit to Bath	2.5
Builders Trials	2
Incline	2
Acceptance Trials	1
Delivery	0

Table 5-2 - BIW Key Events Schedule

Ingalls Key Events Schedule	Months Before Delivery	Duration
Contract Award	52	0
Start Fabrication	38	0
Assy Start Fabrication	38	8.25
Pre-Outfitting Starts	33.25	9.5
Assy Erection Starts	31	10.25
On Unit Outfitting	31	11
Lay Keel	26	0
On Block Outfitting	19.75	4.25
Testing	19.75	4.25
Float Off	15	0
On Board Outfitting	15	14.75
Testing	15	14.75
Main Engine Light Off	9	0
Alpha Trials	3	0
Delivery	0	0

Table 5-3 - Ingalls Key Events

The durations for the BIW process were not available. A discussion of the differences between both process is included at the end of this section.

## 5.12 Shipyard Suggestions

People at both yards were asked to discuss the differences between yards and the reasons why the Ingalls product is less expensive. The answers varied widely. They represent the responses from managers, designers, marketing people, and production planners.

- BIW is the lead design yard for the DDG-51. If it makes a design change it must be formally documented and passed on to the other yards. Ingalls is the follow on yard for design and does not need to update BIW on producibility changes.
- Ingalls does not even bother to draw sketches of 2" pipe and below. It just uses the rough drawings provided by BIW.

- The larger area for layout at Ingalls allows more flexibility in the process and a more efficient use of material flows
- Workers at BIW claim the two ships are not same quality product. They believe Ingalls is not held to same quality standards by the Navy. BIW claims the operators know which ship is better. Quality will play a major factor in the Life Cycle Costs (LCC) of the ships. It may be too early in Life Cycle of the DDG-51 to try to assess the impact quality has on LCC. CG-47, another older class of ships that was split between Ingalls and Bath may shed some light on this issue.
- Labor Rates are cheaper in Mississippi.
- Mississippi is a “Right to Work” State meaning the workers do not have to join the union. This may allow increased flexibility when it comes to labor negotiations.
- BIW deals with the International Association of Mechanics which is a very powerful union. The union has shut down the yard several times in the last ten years.
- BIW states they lose less work days to weather than Ingalls. This can not possibly be true. Even though much of the initial stages of construction at Bath are indoors, the weather in New England for the past few winters has been bad enough so the workers could not get to the yard on many occasions.
- BIW claims the Overhead Rates on the last DDG-51 bid submitted by Ingalls was made with the assumption that LPD-17 contract would go to Ingalls. Now that

LPD-17 has been awarded to the Avondale/Bath consortium, the difference in price will go away.

### 5.13 Qualitative Assessment

I have tried to make some impartial observations of the two shipbuilding processes. These observations are made based on visits and numerous conversations with people working at both yards.

- BIW pre-outfits its blocks to greater extent than Ingalls. They launch the ship around 70-75% completed. This may lead to higher quality and productivity in certain shipyards. At Bath, the larger blocks act as a constraint to the process. A final blast and paint of the construction blocks is conducted to make up for the long time the pieces are kept in storage and to improve quality. Moving the larger blocks around the yard disrupts the entire process at Bath. At Ingalls, no final blast and paint is done thus removing this constraint to the process. Although more work needs to be done On Block, it may cost less in terms of disruption. Comparing the final product of both yards, BIWs process leads to higher quality at the expense of increased man hours.
- BIW is constrained in the draft of ship it can launch by the depth of the Kennebec River. For this reason, the ship must be transferred down the river to Portland, ME to install the sonar dome. This process requires an additional dry docking

which is a labor intensive evolution. All services must be removed from the ship in support of this requirement. Ingalls fully outfits the ships it builds, including the sonar dome, and then uses a land translation system to move it to a dry dock. This is the most dramatic difference between the two processes.

- Looking at the key events schedules and the capacity utilization, it can be seen that Ingalls can produce ships at a much faster pace than BIW. Ingalls management would like to pursue a more aggressive schedule if they could get more work. The current division of DDG-51 work calls for 1.5 to 2 ships for each yard per year. Ingalls has the capacity to build 5 DDG-51s each year. The constraints at BIW limit throughput to about 2 or 3 ships per year. The price for the DDG-51 is set by the process at BIW. Ingalls seems to adjust its schedule to mirror the man hours expended at BIW. Until the required throughput at Ingalls is increased, the Navy will pay the BIW price for ships.

Overall performance on this class of ships has been excellent. The current cost growth has been placed at (-14%) indicating competition is working to reduce program costs.<sup>64</sup> Although competition seems to be having the desired effect for the government, on this project, better cost and schedule performance can be achieved. Additional savings could be made if the throughput were faster. 3 ships per year is not enough to satisfy the

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<sup>64</sup> Simmons, L.D., (1996) "Assessment of Options for Enhancing Surface Ship Acquisition," IDA Paper P-3172, Institute for Defense Analyses, Alexandria, Virginia.

capacity of two major shipyards. Hard decisions need to be made. The logical decision is to award the Arsenal Ship to BIW for construction. Arsenal Ship, combined with the LPD-17 work will keep Bath busy for several years. Award all of the entire next batch of DDG-51 work to Ingalls.

Bath will need time to complete the extensive renovations currently planned for their yard. Maintaining the DDG-51 production line while making radical changes will be difficult. The government could guarantee BIW a steady order book for the time it takes to recoup its investments in infrastructure. Meanwhile, Ingalls can produce as many DDG-51 ships as are budgeted for that year. Cost and schedule improvements should be possible with a larger throughput at Ingalls. In this way, the Navy could gain productivity improvement at both shipyards without huge expenditures.

### **5.13 Performance of Bath vs. Ingalls on SOCV**

In order to quantitatively compare the two shipyards, the Ship Production Model was modified to represent the process at BIW. Real production data on the DDG-51 was not available. For this reason, the SOCV was run through both yards. The total scope of work and the schedule is the same for both yards. The schedule may not be optimal for BIW as it was developed during the Build Strategy for Ingalls. The Build Strategy was modified to reflect a higher level of outfitting calculated to depict the different way ships are built at Bath. The quality of the On Block and On Board stages is raised to 95% representing the higher degree of quality in PO2 at Bath. The modifications for BIW to the strategic parameters representing the ship are included in Table 5-4.

SOCV Strategic Parameters	Ingalls Value	Bath Value
Number of Units	101	400
Design Schedule (wks)	112	112
Engineering Hours	250,000	250,000
Design Staff	200	250
Production Hours	2,052,000	2,052,000
On Block Quality	85%	90%
Fabrication Work (work orders)	12,500	12,500
Structural Staff	850	850
Productivity Goal (mh/tonne)	80	80
Fabrication (work orders)	41,040	45,980
On Unit Work (work orders)	12,314	22,676
Erection Schedule (wks)	41	41
On Block Work (work orders)	21546	19841
On Board Work (work orders)	27702	14172
Project Deadline (wks)	150 wks	150 wks
Over Run Penalties (\$/wk)	350,000	350,000
Blast and Paint (blocks/week)	6	2
Erection Sites	2	1

Table 5-17 - BIW and Ingalls Parameters

The maximum labor for each phase is left at the original level. The constraints to production are modified as discussed in Chapter 3 to the levels of BIW. A base run is conducted at BIW and compared to the Ingalls base run in **Figure 5-38**.

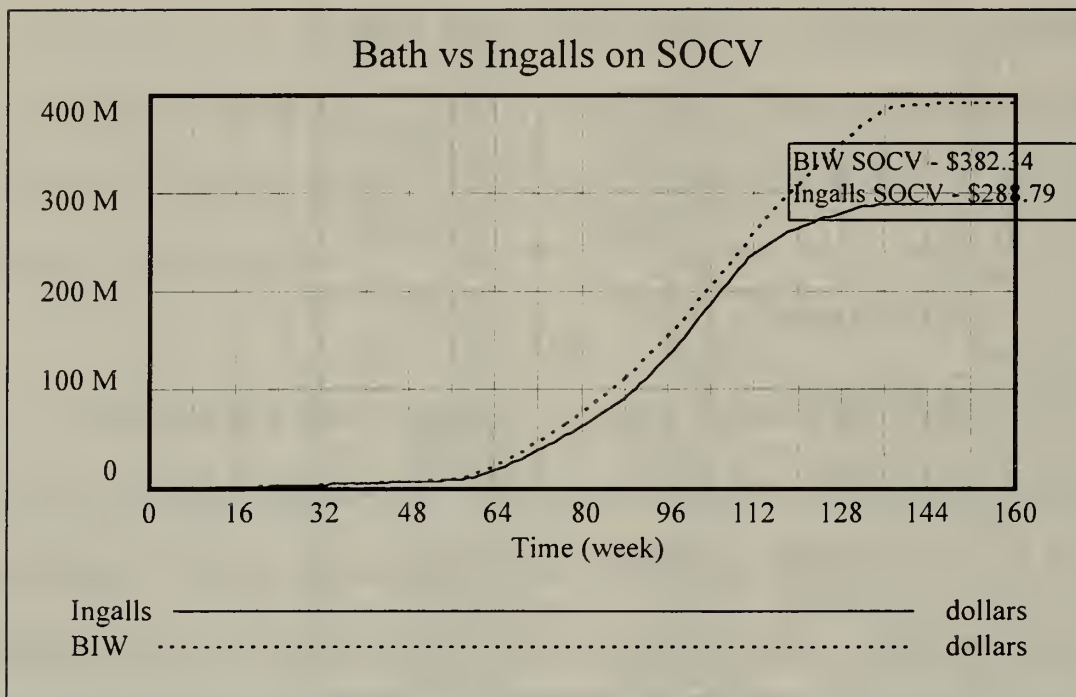


Figure 5-38 -Ingalls vs. Bath on SOCV

The constraints at Ingalls are less restrictive than at Bath. The Build Strategy limited the impact of SOCV at Ingalls to two shipbuilding ways. At BIW, only one erection site is available. SOCV at Ingalls is less expensive by almost \$100 million. The primary reason is that BIW has a very difficult time meeting the schedule required for SOCV based on their current configuration. This difference is much higher than the \$10 million dollar difference on DDG-51. The schedule for SOCV was set by the Build Strategy for Ingalls. The amount of overtime and schedule pressure required to meet this schedule has significant effects on productivity. The productivity in the On Block and On Board stages fall off as the bottleneck at Blast and Paint limits production as shown in Figure 5-39.

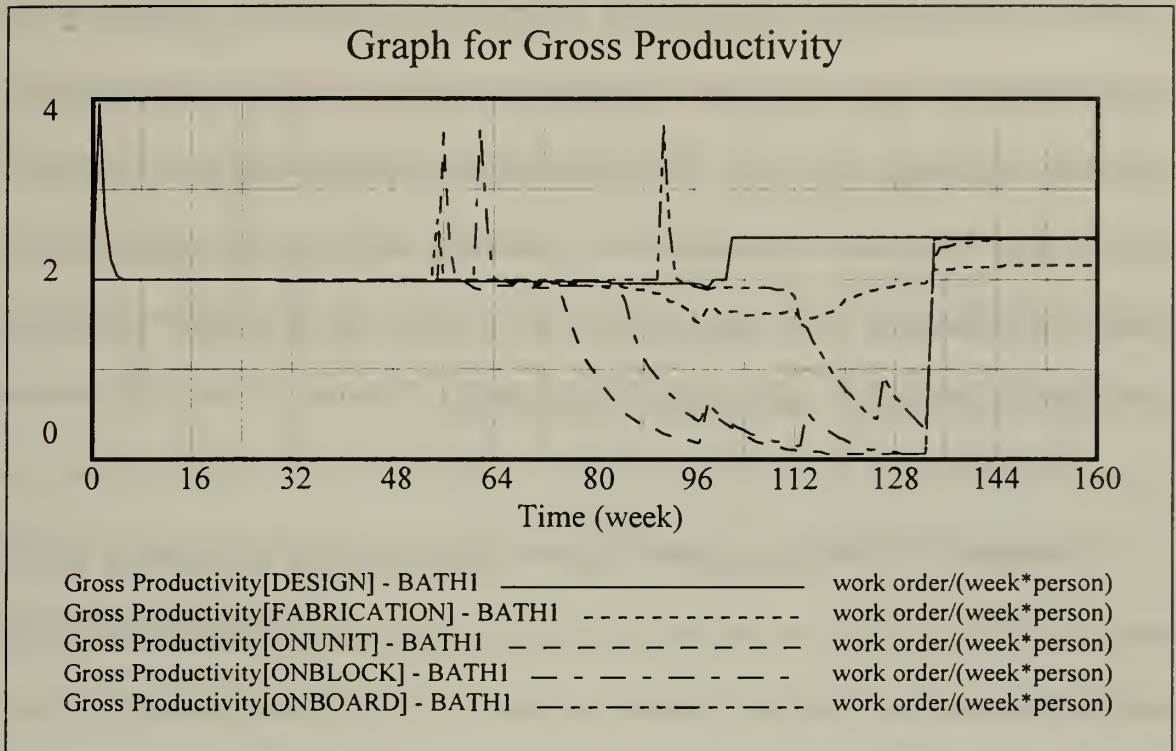


Figure 5-39 - Productivity at BIW on SOCV

In the next few sections, modifications to the processes at Ingalls and BIW are evaluated. The modifications represent case studies in ship production. A dynamic hypothesis is formed for each case. Modifications to the Ship Production Model are used to simulate the effects associated with the hypotheses. The results are then discussed.

## 5.2 Increase the Levels of Pre-Outfitting

*"There is not much more you can get out of steel fabrication in terms of producibility. That's not where we see the shipyard delays anymore. The problem is in outfitting and in running the distributed systems through the ship (HVAC, cabling and piping). This is where the Japanese have us beat. They put a tremendous amount of*

*planning into the way they outfit the ship.*"<sup>65</sup> US shipbuilders do not pre-outfit to the extent of many of the foreign yards. Japanese shipyards have found pre-outfitting to be beneficial to reducing cycle times. Some of the Japanese yards are lifting over 1000 tons in each block. This allows most of the work to be done away from the erection site and reduces the dependency of the completion of one part of the ship on another. The weight of blocks in most US yards are limited to under 300 tons.

Extensive pre-outfitting requires superior tolerance control to ensure the pieces made in different parts of the yard will fit together when needed. It also requires large overhead cranes to move the heavy blocks into place. The crane issue is easier to fix than accuracy control. Without better accuracy control, the US yards will continue to build most of the ship in the On Block and On Board phases. The productivity of the overall process will continue to lag behind the foreign competition until more work can be done off the ship.

## **5.21 Problem Description and Reference Modes**

*"The shipyards themselves do not know the full effect of moving work to earlier stages. The direction is known but the quantitative effect by stage and type of work is not."*<sup>66</sup> Can a difference in end cost and schedule time be realized if the work is pushed

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<sup>65</sup> Safina, Mike, (April 1997), personal communication.

<sup>66</sup> Simmons, L.D., (1996) "Assessment of Options for Enhancing Surface Ship Acquisition," IDA Paper P-3172, Institute for Defense Analyses, Alexandria, Virginia.

further forward in the process? It is generally agreed that productivity in the later stages of construction drops as the ship becomes more complete and more interferences are experienced. It is not clear what the impact of this productivity drop has on the final cost of the ship. One problem is data consistency. Collecting the same production data from several shipyards is difficult. Each yard describes the way it builds ships differently. The indicators they track to manage the process are different. Even if some of the variables, are common across yards, they may be defined differently. With standardization of Product Oriented Work Breakdown Structures, data may be able to be collected in more useful form in the future.

Each US shipyard decides what level to outfit the blocks it erects based on the constraints of the yard. BIW pre-outfits to a greater extent than the other yards because it is limited to two active construction ways. To reduce the amount of time spent in the construction ways to a minimum, the blocks have much more work done prior to erection. At Ingalls, as discussed in Chapter 3, the Erection Area is much less restricted. The Land Level Translator allows many ships to be erected at the same time. A similar situation occurs at Avondale where 8 ships can be erected at the same time. Although Ingalls and Avondale may be able to physically do more work On Board than BIW, it may not be an advantage in terms of productivity or quality. The level of completeness at launch for several of the yards visited is included in Figure 5-40. The level to which the Japanese yard Ishikawajima-Harima Heavy Industries (IHI) has been outfitting is also included as a reference point. Ingalls is able to outperform BIW even with low levels of

pre-outfitting. There is no incentive for Ingalls to become more productive on the DDG-51 contracts unless they are rewarded for their efforts.

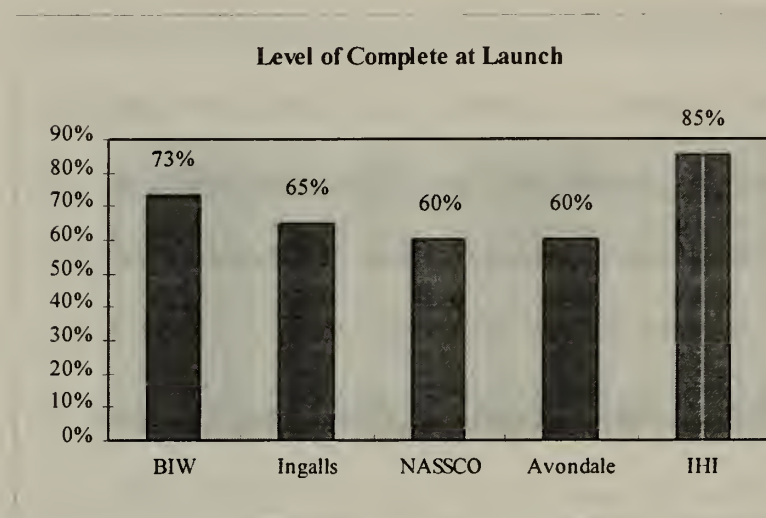


Figure 5-40 - Level Of Pre-Outfitting

## 5.22 Dynamic Hypothesis

The dynamic hypothesis to be investigated in this section is that moving more work to the On Unit and On Block phases will increase the quality and productivity of the entire construction sequence and eventually reduce the end cost of the ship. Recent advances in distributed systems and cable junction boxes may allow US shipyards to add much more complexity earlier. With proper planning, accuracy control, and increased lift capacity, US yards should be able to do more work away from the erection site. The base case of SOCV through Ingalls shipyard developed in Chapter 4 will be modified to investigate this hypothesis.

### 5.23 Analysis

To simulate this case, the initial scope for each phase identified in the base case is modified. The total number of outfitting work orders remains the same. The number of work orders that are done in the On Unit and On Block phases are increased while the number of work orders done On Board is reduced. The amount of work done by the time the ship is launched is increased increments from 65% to 75% and finally to 85%. The Normal Productivity of the On Unit and On Block are higher than On Board for reasons discussed in the Build Strategy.

Three cases are examined and compared for their relative cost and schedule performance. The first is the base case. Ingalls launches ships with 65% of the outfitting complete. The jump to 75% complete represents the level of pre-outfitting of BIW. Finally the 85% complete represents the pre-outfitting of a world class commercial shipbuilder, IHI. Changes made to the base case for each of the levels of outfitting are included in Table 5-18.

SOCV Work Definition	Base	Percent	Preout1	Percent	Preout2	Percent
Design	12500		12500		12500	
Fab	39726		39726		39726	
On Unit	14123	23%	21683.55	35%	24781.2	40%
On Block	26300	42%	24781.2	40%	27878.85	45%
On Board	21530	35%	15488.25	25%	9292.95	15%

Table 5-18 - Pre-Outfitting Levels

5.24 Results

The difference in total cost of the SOCV project at Ingalls using different levels of outfitting is represented in Figure 5-39. The use of increased pre-outfitting reduces the end cost of Ingalls.

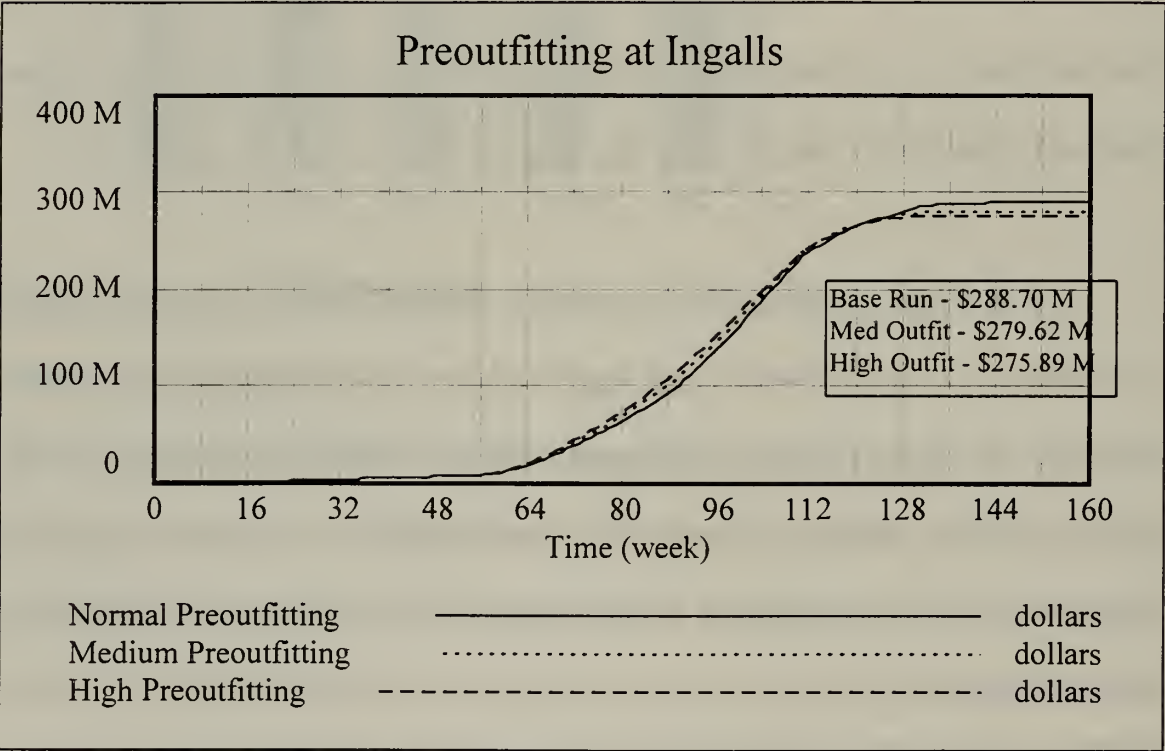


Figure 5-41 -Effect of Higher Pre-Outfitting

The higher quality in the On Unit and On Block phases reduces the total amount of rework generated. As a result of more work being done earlier, the rework that is created is discovered and scheduled for correction earlier. This reduces the spike of Discovered Rework that shows up in Work Remaining towards the end of the Base Case. The “worse before better” dynamic is experienced. Initially costs are higher than the base run because more work is being done earlier. The end costs come out less by a substantial amount. Understanding that things will get worse before they get better is critical. A policy may have short term detrimental effects that must be taken into account with an eye on the long term solution.

Based on the preliminary results of this analysis, it would benefit Ingalls to pre-outfit their blocks to at least the 75% complete at launch level of BIW. This higher

degree of outfitting results in almost \$10 million dollars in savings. The returns drop off as the level of outfitting gets higher. Making the initial jump from 65% complete to 75% complete at launch will require investments in quality control and greater coordination in the On Block construction stage. The On Block area will need to be covered to prevent damage to installed systems by the weather. Lift capacity will not need to be enhanced as the maximum block size can be kept below the 300 ton limit at Ingalls.

To make the jump to world class levels at 85% complete at launch will require much more change at Ingalls. More room will be required for On Unit work. Lift capacity will need to be increased to 450 tons per block. The estimated returns for this level of outfitting are \$13 million over the base case but only \$3 million less than the 75% complete case.

### ***5.3 Choke Point Analysis and Infrastructure Investment at BIW***

Cycle Time reduction is something every shipyard visited is thinking about. Finding ways to do things smarter and faster is a priority in most industries. For shipbuilding in the United States, this may not be the case. The amount of work currently offered by the Navy is not enough to stimulate maximum throughput efforts. To drive cycle times down there must be more work for the shipyards to build once they finish their current orders. One way to maintain labor at the yard is to slow the construction of existing ships to a minimum. This acts to decrease the productivity of work on existing ships but keeps the workforce employed until the next contract comes through. To be

competitive on commercial contracts, however, cycle time and productivity are the two major issues.

The next policy analysis concerns the constraints to production. If domestic yards can stimulate commercial work, they will need to reduce cycle time to remain competitive. The choke points at all shipyards have been identified in Chapter 3. If it is found necessary to ease the choke points, an investment needs to be made in additional infrastructure.

### **5.31 Problem Description and Reference Modes**

At BIW, the primary constraint to production is the Blast and Paint Facility. In order to increase the amount of blocks that BIW can produce each week, the throughput in this area needs to be increased. The cost of increasing the Blast and Paint Capacity to allow double the throughput per week is estimated at around \$5 million dollars. The problem for production planners is quantifying the benefits the additional capacity provides to the shipyard. What is the payback time for this investment? Do other constraints exist that would nullify the investment in new Blast and Paint Facilities?

### **5.32 Dynamic Hypothesis**

By easing the Blast and Paint constraint at Bath Iron Works, the throughput of blocks through the On Block phase and through the yard can be increased. This increase

in throughput leads to a reduction in cycle times and an eventual reduction in costs on the SOCV project.

### **5.33 Analysis**

To simulate this hypothesis, the capacity at BIW of the Blast and Paint Facility is doubled in the Ship Production Model. The performance is then compared to the base case. This type of analysis shows the power of simulation. When the model is properly calibrated, these “what if” questions can be investigated quickly and cheaply. In the past the way to determine whether a policy will work was to conduct a pilot program in a small portion of the shipyard. Pilot programs can not capture the true impact of a policy on the entire shipyard. With simulation, management can get the answers to their questions without a major disruption of the day to day operation of the yard. The values that the simulation produces may not be exact, but the relative behavior of one policy can be compared to the baseline or other policies.

### **5.34 - Results**

The base run at BIW in Figure 5-42 indicates the cost of building the ship is significantly higher than Ingalls. The project costs after doubling the capacity of the Blast and Paint Facility are represented in Figure 5-42.

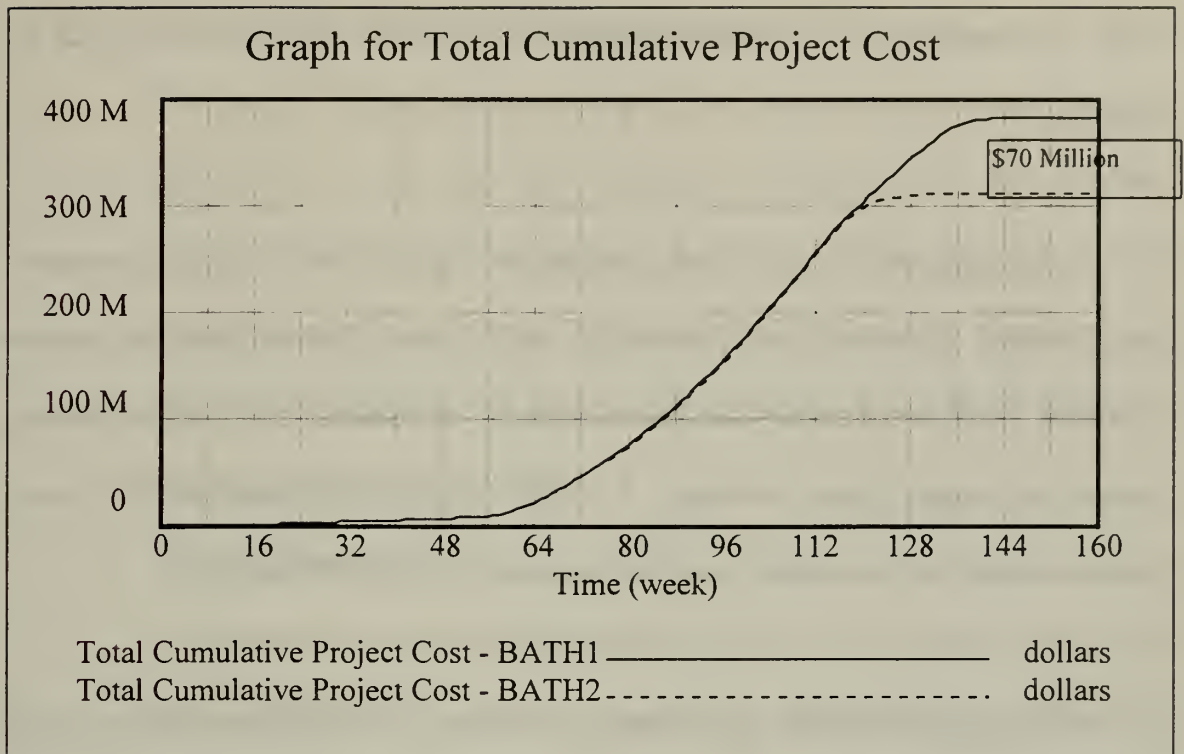


Figure 5-42 - BIW B&P Compare

The primary reason for the decrease in end cost is the smoother flow of material through the yard. The bottleneck at Blast and Paint caused productivity in the On Block and On Board phases to drop to very low levels in the base case. The effect that captured this problem is the Effect of Prerequisite Readiness. Because material was constrained at Blast and Paint, the On Board portion of the project was delayed. More work to do late in the project resulted in the use of higher levels of overtime. Fatigue and schedule pressure effects combined to reduce productivity.

After the capacity of Blast and Paint was increased, the productivity problems are not as severe. The Effect of Prerequisite Readiness still causes a dip in productivity. The schedule pressure and fatigue effects still are active indicating the process is not yet

ideal. The modified BIW run experiences some problems but not near the level as in the base run.

The capacity of Blast and Paint was doubled again to see if more improvement could be made to the end costs. The results were the same end cost indicating another constraint had been reached. The next bottleneck was determined to be engineering capacity to produce timely drawings. In order to remedy this situation, BIW could supplement their in house design team with contractor or hirer more people.

This analysis indicates that investing \$5 million in increasing the Blast and Paint Capacity would contribute to a reduction in the end costs of the ship of more than \$70 million dollars. Actually putting a number on the benefits is not as important as realizing that an order of magnitude difference can be achieved between the amount invested and the benefits which result. It is also interesting to see that as we raise the constraints to production in some areas, other constraints may be activated. Understanding these constraints and the benefits that could be achieved by easing them is a huge advantage for the shipyards.

#### ***5.4 Additional Uses for Ship Production Model***

There are many other possible uses for the Ship Production Model or similar models. These include:

- Effect of Navy or Shipyard Generated Changes

The cost of adding scope or changing the contract after contract award is detrimental to the cost and schedule performance of the program. Government initiated change should be kept to an absolute minimum once the contract is awarded and detailed design begins. Producibility changes should be encouraged during the detailed design stage but should be kept to a minimum after production starts.

- Shipyard Manning Level

US Shipyards are characterized by their casual use of the labor force. This means that they only employ the work force when needed.<sup>67</sup> Determining when to start laying people off or to find busy work for them to do until the next surge in work is a critical strategic decision that each shipyard must decide. US Shipyards tend to take a short term view of the problem and reduce the number of people to cut overhead costs as soon as the order book experiences a dip. When more work is contracted, new labor needs to be procured. The people that were let go may not be available to be rehired. Significant training time is required to produce an effective ship builder. The process may take as long as 4-5 years based on the trade needed. The true cost of bringing new people into the shipyard in terms of loss of Productivity, Rework, and Training is not well understood.

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<sup>67</sup> Frankel, E.G. (1990) "The Path to US Shipbuilding Excellence - Remaking the US into a World Class Competitive Shipbuilding Nation", NSRP 1990 Ship Production Symposium, August 21-24, 1990, Milwaukee, WI.

- Bid Formulation

The shipyards could use data from a previous ship project and make the necessary changes to represent a proposed ship. The model could be used to determine what the approximate cost of the ship would be if the process remains the same. The yard could also account for changes in infrastructure and manning and determine what impact a change in the process would have on the costs.

- Benchmarking the Competition

As part of a benchmarking effort, the shipyard could collect as much information as possible about the competition and make the appropriate changes to the model. Using the same ship package developed for their bid, the yard could determine the approximate costs at the competitor's yard. In this way, the shipyard could determine where they need to improve. The constraint in Blast and Paint at Bath is an example of a place where improvement could be made to lower end costs.

- Schedule vs. Cost

One question the Navy almost never asks is what is the cost of accelerating or slipping the schedule to meet the demands of the shipyard. If the order book is starting to dwindle in the yard, it may be more practical to increase the work intensity on the ship. In this way the labor pool could be kept at a steady level. Likewise, when a problem occurs it may be more beneficial to slip the schedule to the right instead of working overtime to meet an impossible

deadline. If Navy and shipyard planners could quickly examine the trade-off between cost and schedule a better decision could be made to the benefit of all parties.

- **Emerging Work Impact on Shipyard**

Many yards will automatically bid on emerging work despite the order book. Sometimes having too much work can lead to problems with base work. Determining when emergent work will have a detrimental impact on the core business is critical. The emergent work could be modeled as added scope to determine if the current constraints of the yard can support the additional throughput.

## **5.5 Summary**

In this chapter, the simulated building of SOCV at Ingalls and Bath is conducted to examine the differences between the two yards. The Ship Production Model is used to examine several dynamic hypotheses concerning the management of SOCV. The results of this analysis indicate that despite the higher quality of work at Bath, the constraints of the shipyard limit the productivity. Improvements to the process at both yards are examined. The results of this analysis indicate potential savings are possible at both yards. Ingalls must work on quality and its level of outfitting. BIW must work on the constraints to production in the Blast and Paint facility and at the erection site.

The Ship Production Model, while by no means perfect, can be used to examine many of the complex issues raised by the Navy and the shipyards concerning the management of a shipbuilding project. The current level of detail is meant as a research tool for proof of concept. The aggregation of data is at the strategic level. As better process information is collected and calibration to historical data is completed, the model will become a valuable analytical tool that will enable quantitative decisions instead of just “gut feel.”

Simulation holds great potential in the shipbuilding world. 3-D project models can provide information for designers, manufacturers, customers. and anyone else involved in the construction of a ship will become a reality in the very near future. The process used to produce this product must not be ignored. Improvements to the process can be facilitated by the use of simulation to examine management hypotheses. Model results can be used to advocate one change over another. A clearer understanding of the decisions made on a project by the government and the shipyard can be realized. Without simulation, choices are made based on values that can be quantified easily and not on the potential benefit to the shipyard or product end cost..

## Chapter 6 - Conclusions

The current Affordability Crisis in which the Navy finds itself has been described and analyzed. A possible remedy for increasing the throughput of the private shipyards, high performance commercial ships, is discussed. The Build Strategy of one particular high speed container ship, SOCV, is presented. The ways in which ships are built in the major shipyards in this country are investigated and compared. The combination of the characteristics of the ship and the shipyards are used in a System Dynamics model, the Ship Production Model.

The Ship Production Model is used to conduct case studies concerning the difficulties many yards experience in ship construction. The values of interest the Ship Production Model can provide are:

- Cost
- Schedule
- Quality
- Productivity

Causal tracing can be used to find the root causes of quality or productivity problems on a project.

Shipbuilding is a natural field for increased use of simulation in that few products of each type of products are built. The largest production line in operation is the DDG-51 class with plans for 30 or more ships over a 15 year period. When compared to the

hundreds of thousands of cars Ford rolls off the assembly line each year one realizes shipbuilding is a craft, not a mass production industry. The throughput of the same product on which to make improvements in shipbuilding is far less available than other industries. Increasing throughput is crucial to improving productivity in this country.

The Ship Production Model is used to check the validity of the Build Strategy created for SOCV and to test hypotheses for improving the process in any shipyard. It is also used to make quantitative comparisons of the way two competitors build the same ship. At this stage the model is a research tool used for proof of concept. Many of the structures and table functions in the model were developed for other industries. In order to tune the model to provide more accurate results for any specific shipyard, more research at a finer level of detail than the strategic level needs to be conducted.

The next step for the Ship Production Model is to go to back to the shipyards to benchmark the quality, productivity, and constraints at each phase of construction. If additional structure is deemed necessary to capture the problem of interest, modifications should be made. Confidence can be built in during model development by including as many people in the yard as possible. All of the participants in the acquisition process, the ship owner, the shippers, the Navy, and the shipyard should be included in the model development and calibration if possible.

## ***6.1 Implications for Navy Acquisition Process***

Models like the Ship Production Model can be used by the Navy to make smarter decisions about how contracts are awarded. Bid price can not be the only criteria for the award. If the shipyard can be properly simulated, the impact of new work in the shipyard can be measured. The true cost of awarding a new contract to an already overloaded yard can be determined. When one yard comes in with a bid much lower than the competition, it could be asked to quantify via simulation the improvements it plans to make to achieve such savings. This reduces the risk the government must assume when dealing with the private yards.

The model can become the receptacle for all of the shipyard and the governments assumptions and objectives concerning the project. Once a view of the other sides position is apparent, better communication will result. By jointly building a model, all of the important issues will need to be discussed up front. If disputes arise later over any aspect of the process, the model can be used to find common ground.

Determining the true impact of acquisition reforms is another field in which simulation can help. The impact an acquisition reform has on any ship program can be modeled. A dynamic hypothesis of how to improve the process can be formulated and modeled prior to implementation. In this way, only the reforms that have considerable favorable impact on the process will be considered. If too many reforms are attempted at the same time, the true impact of each measure may never be realized.

## **6.2 Future Work**

As previously mentioned, much must be done to take the proof of concept, strategic level research model to a working, useful, accurate tool for program managers at a specific shipyard on a specific ship. I plan to take the model with me to NASSCO for my next tour of duty. The model will be tuned to meet the constraints of NASSCO. The base work in the yard will be modeled. I will attempt to use the model to make predictions about project performance.

One recent development that could spur increased use of System Dynamics modeling for shipbuilding is the reopening of the Quincy shipyard as Massachusetts Heavy Industries (MHI). The 5 dry docks and huge 1200 ton overhead crane left over from the old Navy yard will soon be put back in operation on the construction of product tankers. The methods proposed for shipyard operation are state of the art. The Samsung yard in Korea provides the design and many of the processes planned for incorporation in this yard. This would be a perfect place to determine if the Ship Production Model can really produce fast and accurate results.

The product is well defined, a 46,000 DWT product tanker. The shipyard is being reconfigured from the ground up. The model could start with the conceptual way the production planners intend to lay out the yard. State of the art CAD/CAM fabrication machines, robotics, JIT material deliveries and high levels of pre-outfitting are all being discussed for this shipyard. As the machines are put in place, time studies can be

conducted to determine the real productivity of a worker at each machine. The impact of things like prerequisite dependencies, fatigue, morale and quality on productivity can be directly measured. This data can be used to fine tune the Ship Production Model to the point where confidence in the results can be achieved. The model would then become a valuable planning tool for any changes envisioned for the yard.

Quincy is within easy driving distance of MIT. Perhaps a joint venture between the Ocean Engineering Department and the Systems Dynamics Group under the Lean Ship Initiative could be formed to study modeling at MHI. A unique opportunity exists to further the research. The lessons learned here could be implemented Navy wide.

### **6.3 *Flight Simulator***

New program managers can use a model similar to the Ship Production Model as a flight simulator. This will allow them to try out any idea they have to improve the process. A model like this could be used in conjunction with a text like Ship Production to allow the reader to investigate some of the hypotheses proposed in the book.<sup>68</sup> Several case studies could be developed which look at the effect of exogenous shocks like higher material costs or labor problems that require management to make changes in the yard. The policies needed to survive such a shock could be investigated. Strategies for dealing with complex problems could be formulated. Simulation could provide valuable experience to novice managers who do not have the luxury of poor performance on a

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<sup>68</sup> Storch, R.L., Hammon, C.P., Bunch, H.W., Moore, R.C., (1995), "Ship Production," 2nd Edition, Cornell Maritime Press, Centreville Maryland.

contract. The amount of money involved and oversight on any ship program reduces the opportunity for new managers to “fly by the seat of their pants.” Without the opportunity to make mistakes, managers take much longer to learn the best policies to use.

Overseeing the process of designing, planning, building and testing a new class of ship is one of the most challenging tasks any manager could hope to undertake. The difficulty of the ship design, huge budgets, many customers providing oversight and congressional interest all contribute to the complexity of the situation. The only way to unravel the complexity is through the use of detailed simulation. With proper simulation, better decisions can be made in a timely manner for the benefit of all. Simulation may provide the competitive advantage shipbuilders need to get back into the world shipping market.

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## Appendix A: Build Strategy Development

A Build Strategy is created for a commercially viable Sealift ship, SOCV (Sealift Option for Commercial Viability). The format used was developed for the NSRP by a Build Strategy Project conducted at NSWC Carderock.<sup>69</sup> SOCV is a high performance container ship capable of maintaining 35 knots in heavy seas. This ship can also be easily converted to meet surge Sealift needs for the Department of Defense as a RO/RO ship. Several National Defense Features (NDF) have been designed into the ship to allow quick conversion. A description of SOCV and its capabilities are provided. This ship represents the high performance commercial ship contracts domestic yards are hoping to attract to supplement their Navy work. SOCV has the powering requirements of a combatant ship and an advanced hull form making it similar to the ships US yards are currently building.

The key events that characterize the ship construction cycle is developed. The Build Strategy is geared for Ingalls shipbuilding based on the source selection made in Chapter 3. The Build Strategy permits its use, with minor modifications, within the current capabilities of most domestic yards for comparison purposes in Chapter 5. Specific coordination of SOCV work with the base work of Ingalls is required. Production planning is conducted using a hull block construction method with zone outfitting. The block break criteria and construction sequence are formulated. This ship

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<sup>69</sup> Lamb, T., (February 1994), "Build Strategy Development, The National Shipbuilding Research Program," Carderock Division, Naval Surface Warfare Center, Bethesda, Maryland.

has been designed by a civilian firm, SOCV@MIT. It contains installed NDF equipment like ramps, ventilation ducts and added sprinkler capacity which are part of the military requirements for the ship.

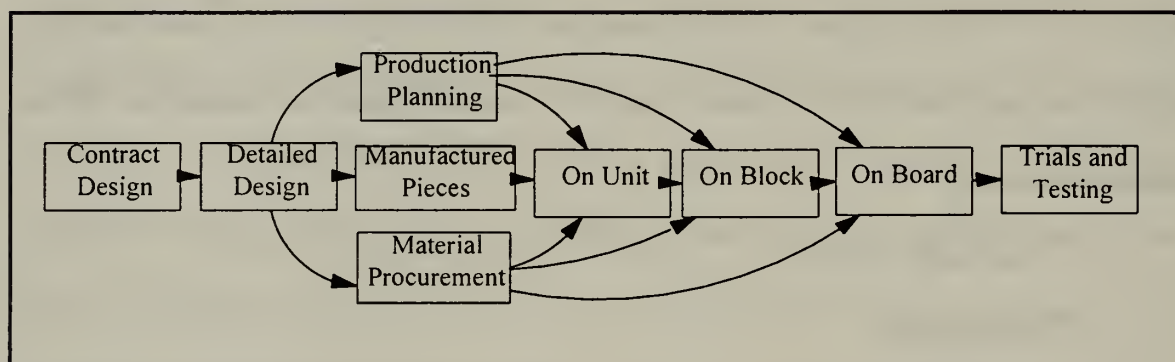
The Build Strategy provides the work breakdown of the ship into smaller packages. These packages will be fed into the Ship Production Model in Chapter 4 as the work profile. When combined with the management and infrastructure parameters of the specific shipyard identified in Chapter 3, all of the inputs required for simulation will be available including:

- Total scope of work
- Work profile
- Shipyard resources and constraints
- Labor
- Management Decisions and Policies

These inputs will be discussed further in the summary of this section.

Figure A-43 depicts the process used to build the SOCV. This process is typical of shipbuilding in this country. The different shipyards may vary in how much work is done in each stage but the basic flow of material is the same in every yard observed. These differences will be discussed in Chapter 3 and quantified in the analysis portion of Chapter 5. The Contract Design is the product of an Integrated Product Team (IPT) including the shipyard, the commercial ship owner/operator, the Navy, MSC, and the

possible customers who will use SOCV to ship their high value cargo. By including all the “customers” for this ship in an IPT, many of the concerns about producibility, maintenance, conversion to a sealift ship, and ease of cargo handling can be discussed before the first piece of steel is cut. All phases after Contract Design are the responsibility of the ship builder.



**Figure A-43 - Ship Construction Process**

The different phases of construction are discussed later in this chapter. A major productivity problem identified by several studies and observed during the shipyard tours is that US shipyards tend to delay outfitting until much later in the construction sequence than the Japanese.<sup>70</sup> A way to measure this is the percentage of outfitting work done in the On Unit, On Block, or On Board construction phases. This subject will be discussed in detail in this chapter and investigated by the use of simulation in Chapter 5.

<sup>70</sup> Wilkins, J.R., Kraine, G.L., and Thompson, D.H., (Aug 1993) Evaluating the Producibility of Ship Design Alternatives, Journal of Ship Production, Vol 9, No 3, pp188-201.

## **Build Strategy - Purpose**

*"A Build Strategy is an agreed design, engineering, material management, production and testing plan prepared before work starts, to identify and integrate all necessary processes."*<sup>71</sup> The Build Strategy provides a framework for the effective development and communication of the many aspects of a ship construction contract. It is a critical part of the Production Planning of a ship. The Build Strategy could be the difference between a successful and a disastrous project. Producing a useful Build Strategy requires a superior understanding of the required resources and associated constraints of the shipyard and the product of interest. The product of interest for this particular Build Strategy is a high performance, commercially viable container ship, SOCV.

## **SOCV Description**

The SOCV represents a significant innovation in the design of container ships. SOCV is a commercially viable container ship with a capacity of 1526 TEU. It can also be quickly converted to a Fast Sealift Roll On/Roll Off (RO/RO) Ship used to transport Army vehicles from the continental United States (CONUS) and the area of conflict. The design represents a material alternative to the Strategic Sealift assets outlined in "Joint Vision 2010" and the Defense Mobility Requirements Study (DMRS). The major requirements placed on this design is that it must be commercially viable while easily convertible for use as a maritime asset for surge Sealift missions.

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<sup>71</sup> Lamb, T., (February 1994), Build Strategy Development, The National Shipbuilding Research Program, Carderock Division, Naval Surface Warfare Center, Bethesda, Maryland

In the commercial mode, this design represents a significant advance in ship technology. The requirements for SOCV calls for a minimum of thirty-five knot sustained transit speed. It has the unique ability to maintain speed in heavy seas. High powered gas turbine engines, steerable waterjets and state of the art cargo handling systems put this vessel in its own class in terms of the performance it can deliver. The SOCV design plans to exploit the emerging Just In Time (JIT) market for goods between Europe and North America. SOCV will set the standard for high performance cargo vessels in the future.

Table A-19 provides the principal characteristics of the SOCV hull form.

LOA	256 m	SHP	240 MW
LBP	229 m	Sustained Speed	36.5 kts
Extreme Beam	45 m	Trim	0 m
Beam @ DWL	39.8m	Full Load KG	16.84 m
C <sub>b</sub>	0.38	η	0.7
Design Draft	12 m	Lightship KG	17.1 m
Depth @ Main Deck	30 m	Cargo Capacity	1524 TEU
Full Load Δ	35,634 tonnes	Cargo tonnes	10,000
Lightship w/margin	17,468 tonnes		
Number of Shafts	5 Waterjets		

**Table A-19 - SOCV Characteristics**

### Shipyard Selection

The number of US Shipyards that can construct SOCV is limited because of the size of the ship. Table A-19 above gives the proposed dimension for length, beam and draft. Because of it's size requirements, it has been determined that only 4 US Shipyards currently have the capability to build this class of ships without a major investment in new infrastructure. Construction of these ships will commence in 1998. The possible

building positions in each of these yards is listed in Table A-20. Projections have been made based on the current and future order books of these yards in Chapter 3. The positions available at each yard are also indicated.

SOCV Capable Shipyards	Shipbuilding Positions	Available Positions
Avondale	8	2
Bath	3	2
Ingalls	6	4
Newport News	3	1
NASSCO	3	1

**Table A-20 - Possible SOCV Shipyards**

Source selection was announced after a more detailed look at the capabilities and constraints of these in Chapter 3. Ingalls was selected to build SOCV. Additional simulation was used to compare the performance on SOCV at Ingalls and Bath.

### **Contractual Issues, Dates and Schedule**

The basic concept for the acquisition of the SOCV is that the US government will fund the construction of these ships. The entire ship will be considered a National Defense Feature. (NDF). The ships will then be chartered to the commercial shipping market as high performance commercial container ships. A clause in the charter agreement will state that in time of war, the charter is canceled and the ship will return to a designated facility for quick conversion to a RO/RO ship. The charter rate will be set by market forces. The SOCV concept is proposed as a replacement to the inactive ready reserve and the current Strategic Sealift Program. The SOCV program will:

- Generate revenues for further construction

- Act as a test bed for new HM&E technology
- Stimulate commercial work in domestic yards
- Provide a superior product for DOD logistics planners

The initial phase of the SOCV program consists of four ships to be built for the government. The ships are due for delivery as follows:

- Award Contract on 15 May 1997
- SOCV 1 - 15 March 00
- SOCV 2 - 15 September 00
- SOCV 3 - 1 June 01
- SOCV 4 - 1 December 01

To complete this aggressive schedule the first block of steel will be erected on 2 August 1998. A critical part of meeting this schedule will be to define, order, and receive all required long lead time material including those pieces internally manufactured and those purchased from subcontractors.

A list of the long lead time material is provided in the next section. Material should be delivered Just In Time (JIT). This will require additional attention to detail to ensure the correct parts are ordered in the correct quantity the first time. The scheduled delivery time of the first ship requires 34 months. 18 months is required for the procurement of long lead time material. The planned cycle times for the follow on ships is 25 months. The delivery dates are spaced so as to only occupy two erection sites at a time. The primary driver for cycle time on the first ship is long lead time material.

**Payments:**

The payment terms are related partly to the milestones achieved during the building process and partly to the desires of the builder. Half of the payments will follow the traditional payment schedule outlined below in Table A- 21. Meeting the necessary milestones is required for this portion of the payments.

Milestone	Percent	Million US\$
Contract Signing	5%	6.25
Cut First Steel	5%	6.25
Lay Keel	15%	18.75
Launch	15%	18.75
Delivery	60%	75

Table A- 21 - Payment Schedule

The other half of the payments will be at the discretion of the shipyard. Whatever financing scheme works out better for the financial stability of the company will be used. This is an incentive to the contractor for building this ship. It will allow the shipyard more freedom in dealing with subcontractors, facilitate volume purchases or fund improvements in infrastructure. Allowing the shipyard the flexibility of planning the use of capital will act to stimulate improvements in the yard that may be reflected in the end cost of the ship.

**Liquidated Damages:**

There are no liquidated damages applying to this contract although the following performance penalties apply:

- For the first 10 days over schedule, no penalty is applied.
- For every additional calendar day the shipyard will be required to pay \$50,000 US, up to a maximum of 5% of the contract.

### **Cancellation:**

Cancellation of the contract can be caused by:

- Delayed delivery longer than 90 days
- Deadweight tonnage 1500 heavier than specified
- Cargo Volume 5000 cubic meters less than specified
- The ship owner will assume the risk for the attained speed and fuel consumption

### **Drawing Approval:**

The government has two weeks to approve or make comments on detailed design drawings. After this period they will be assumed approved. It is critically important to maintain a good working relationship in the early stages of a ship program. Many of the problems experienced on Navy ships could have been avoided by experienced people making informed decisions at the correct time. This is the case with ABS and the USCG as well. Approval for changes must be sought and followed up in a timely fashion to eliminate problems later in the project. Two weeks is a reasonable amount of time to properly analyze and make decisions on a change. Changes which take longer than two weeks may be too extensive to include on the hull under construction. They should be deferred to the next hull if necessary.

## **Construction Inspection:**

The construction of the ship will be subject to oversight provided by:

- ABS: Hull surveyor, electrical and machinery surveyor
- USCG: Ship Surveyor, machine surveyor, electrical surveyor, and a nautical surveyor
- SUPSHIP: Hull, mechanical and electrical surveyors

For tests on equipment and systems, a 24 hour notice is required from the builder. Should the surveyors not attend, the tests will not be repeated. As many tests as possible should be conducted in the workshops with access to necessary services. Before calling the inspectors, the system will have been fully checked and tested by the shipyards QA department

## **Trials:**

The following dock trials will be undertaken along side the pier:

- Main Engine Test
- Auxiliary Machinery
- Deck Machinery
- Container Location and Security
- Controls and Instrumentation
- Standby and Emergency Systems
- Electric Power and Lighting Systems

- Chain Stoppers
- Steering Gear
- Ramps
- Lifeboats and Davits
- Pumps and Fluid Systems
- Air and Sounding Pipes
- Heating, Ventilation, and A/C Systems
- Refrigeration Plant
- Communications System

Sea Trials will consist of:

- Measured mile speed trial
- Torsion Measurement of main engine torque
- 12 hour endurance and fuel consumption at 25%, 50%, 75%, and 90% power
- Maneuvering, turning and stopping
- Crash Astern, Crash Ahead, Astern Trial
- Windlass Trail, full extent of cable out
- Setting of Remote Controls
- Adjustment and calibration of navigational equipment.

### **Quality:**

The quality of the finished steel products will be in accordance with ISO 9000.

USCG and ABS rules will be followed as necessary. The SOCV will be classed by ABS

and will receive a certificate of inspection from the USCG. Other items will be in accordance with pertinent industry standards.

## ***Production Planning***

The tasks accomplished during Production Planning are depicted in Figure A-44.

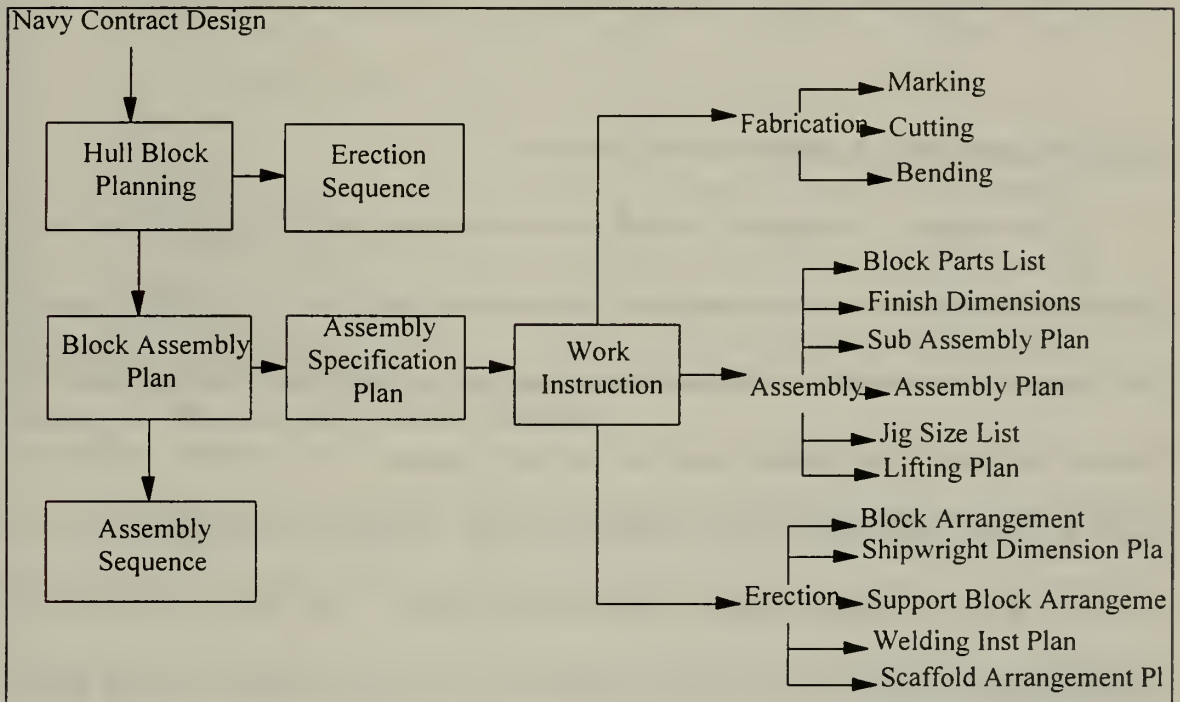


Figure A-44 - Typical Hull Planning Functions<sup>72</sup>

The ship is divided during Hull Block Planning into a discrete number of units. These units take into account the constraints of the shipyard. The size and weight of the units are determined by the capacity of overhead cranes that can move these units into place. The boundaries of the zones are identified in the Production Plan and cover the functional areas of the ship. The zones for SOCV include:

- Machinery

<sup>72</sup> Bunch, H. (1994) Ship Production Notes

- Cargo
- Bow
- Stern
- Accommodations

By breaking the ship into zones, a logical sequence of construction can be planned.

### **Master Construction Schedule and Key Events**

The Master Construction Schedule is developed by the shipbuilder as a management tool to monitor the progress of the construction process. The primary driver for the start of construction is the anticipated delivery of long lead time material. The longest lead time items include main and auxiliary engines. The schedule reflects the desire to install these items as soon as they come into the yard. This reduces the need amount of time the shipyard needs to store this equipment. Once fabrication starts, the Master Schedule reflects inputs from the customer and from the ability to push blocks through the yard selected for construction.

The Master Construction Schedule for SOCV is shown in Table A-22

Event	Description	Event Duration (weeks)	Weeks to Delivery
001	Award Contract (M)	0	150
002	Detail Design	112	150
003	Mat'l Procurement	112	150
004	Production Planning	80	150
005	Lofting	32	100
006	Start Construction (M)	0	82
007	Structural Fab	36	82
008	Lay Keel (M)	0	76
009	Structural Erect	42	76

010	Machinery Install	26	64
011	Piping Install	26	62
012	Elect/Elex Install	26	62
013	HVAC Install	20	60
014	Complete Erection	0	34
015	Tank Closeout	8	32
016	Stern Release (M)	0	32
017	Systems Testing	6	24
018	Launch (M)	0	18
019	On Board Outfit	10	18
020	Compartment Close	6	8
021	Drydocking	1	3
022	Inclining	0	3
023	Dock Trials (M)	0	2
024	Acceptance Trials (M)	0	2
024	Builders Trials (M)	0	1
026	Delivery (M)	0	0
(M) indicates a Contract Milestone			

**Table A-22 - Master Construction Schedule**

This schedule is aggressive when compared to warship construction. The LPD-17 procurement and construction cycle will take almost 5 years to complete. The DDG-51 construction cycles examined in the next chapter take up to 55 months. This schedule is not as aggressive as some commercial ship contracts. The Japanese have been able to reduce cycle times for product carriers to under 11 months from award of the ship to delivery. The Szczecin shipyard in Poland was also able to reduce production cycle times for mid sized product carriers to 11 months. Samsung, one of the major Korean shipyards has reduced cycle times on product carriers to six months. A faster cycle time ensures the product will meet the requirements of the market it was meant to exploit. If cycle times get to be too long, the entire economic situation may have changed. With reduced cycle time there is less technological innovation during the construction sequence. This may reduce the amount of change required to keep the ship current.

Reducing cycle times requires a thorough understanding of the entire shipbuilding process. To relieve the constraints to production will require investment in infrastructure, worker training, and sub contractor relationships.

For the follow on ships, the limitations of long lead time materials are not a problem. A 25 month schedule is planned to push the ships out as quickly as the constraints of the shipyard will allow. The SOCV program is assigned two erection ways. The major constraint to the timing of delivery of the follow on ships is the time spent in the erection process.

The Key Events for the follow on ships are included in Table A-23.

Event	Description	Duration (weeks)	Weeks to Delivery
001	Award Contract (M)	0	100
002	Detail Design	58	100
003	Mat'l Procurement	58	100
004	Production Planning	54	100
005	Lofting	32	100
006	Start Construction (M)	0	82
007	Structural Fab	36	82
008	Lay Keel (M)	0	76
009	Structural Erect	42	76
010	Machinery Install	26	64
011	Piping Install	26	62
012	Elect/Elex Install	26	62
013	HVAC Install	20	60
014	Complete Erection	0	34
015	Tank Closeout	8	32
016	Stern Release (M)	0	32
017	Systems Testing	6	24
018	Launch (M)	0	18
019	On Board Outfit	10	18
020	Compartment Close	6	8
021	Drydocking	1	3
022	Inclining	0	3
023	Dock Trials (M)	0	2
024	Acceptance Trials (M)	0	2
024	Builders Trials (M)	0	1
026	Delivery (M)	0	0
(M) indicates a Contract Milestone			

Table A-23 - Follow On Ship Schedule

A reduction in Navy combatant ship cycle times would allow the Navy to meet the current threat with less risk. Given the long lead times currently experienced, Navy planners are required to design flexibility into their platforms for additional contingencies should the world threat situation change between design and delivery of the ship. The Navy currently uses inordinate amounts of change or added scope to the contract to keep

the most current technology on the its new ships. This is a very expensive way of doing business. Cycle time reductions would help both the Navy and the shipyards. The Navy would receive the ships it needs in a more timely manner and the need for expensive changes would be reduced. The contractor could make productivity improvements which would help his bottom line on the more stable design. To accomplish cycle time reductions to the same level as Japanese shipyards will require a complete overhaul of the way the Navy designs and procures ships.

The Master Construction Schedule is combined with the Block Erection Plan to create the Key Events Schedule. Critical Hull Structural unit numbers are taken from the Block Assembly Plan of the next section.

## **Block Breaks**

Construction Blocks are three dimensional assemblies formed by joining two or more structural panels. The Block Assembly Plan and the Assembly Sequence define how the different sections of the ship will be built and eventually put together. If we consider the ship to be a puzzle, the block breaks identify the size and shape of the puzzle pieces. The Block Break Criteria is a function of the characteristics of the ship and the constraints of the shipyard. The key is to make the pieces of the ship as producible for that particular yard as possible. Once the Block Break Plan has been established, it will be reviewed for producibility.

## Block Break Criteria

The dimensions of the construction breaks are determined by several factors including:

- Length and width of plates available from steel manufacturers
- Transverse bulkhead spacing
- Maximum size and weight of outfitted blocks which can be handled and transported using yard equipment
- Location of major longitudinal bulkheads and major structures like main engines
- Amount of pre-outfitting to be accomplished prior to erection<sup>73</sup>

A similar method as the LX Generic Build Strategy study was used to select where the breaks would occur. The general guidelines are listed below:

- All block breaks are made above the deck and aft of transverse bulkheads
- All stiffeners on the transverse bulkheads are located on the forward side
- Blocks do not exceed 15 meters in length as this is the maximum plate length available for over the road or rail transport.
- Block heights are generally one deck high except in finer portions of the bow and some tanks where arrangements allow multi-deck blocks.
- Block widths were kept to multiples of three meters whenever possible to allow use of full plate widths. The maximum size of the plates are utilized to

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<sup>73</sup> Hough, J. (April 1994), LX Preliminary Design (PD) Generic Build Strategy, Naval Sea Systems Command, Washington, D.C.

reduce wastage. The maximum plate width allowed for over the road travel is 3 meters.

- Block weights are not to exceed 250 tons
- Pre-outfitting to this limit is encouraged although not mandatory
- Preliminary Frame spacing is set at 1.5 meters
- Plate thickness, frame sizing and stiffener sizing are limited to a few standard sizes.

The Block Numbering Scheme is taken from a zone definition exercise developed for an NSRP SP-9 Panel Short Course on Implementation of Zone Technology. The blocks are numbered using a six digit scheme which is described in Table A-24.

Zone Code Description (M XX ZZ Y)							
M - Functional Zone Indicator		XX - Long Location		ZZ - Vert Location		Y - Trans Location	
S	Stern	01	Forward	01	Lowest	0	Center
M	Machinery			02	4 Deck	1	Starboard
C	Cargo	03	Middle	03	3 Deck	2	Port
B	Bow			04	2 Deck		
A	Accommodations	06	Aft	05	House		

Table A-24 - Zonal Block Numbering Sequence

For example, the first block in the bow zone on the lowest level is designated B01010. The zones and general Block Breaks are shown in the profile view of SOCV can be found at the end of this section with the identification of specific blocks by deck. The blocks identified for this study are tentative. If the shipyard has better ideas about consolidation of the blocks into larger Grand Blocks the Build Strategy can be modified in Detailed Design.

## Block Assembly Sequence

The next step in the process is to determine in what order the blocks will be manufactured and assembled. It is critical to take into account the constraints at each phase of construction. Long Lead Time material needs to be ordered and planned for installation. The timing of Key Events like the landing of Main Machinery must be planned so the supporting structure is in place. All of these considerations go into producing a block erection Claw Chart which represents the sequence in which the pieces of the ship will be put together. The sequence of blocks shown in the profile view represent the week in which each block will be erected. The amount of time spent in the construction ways should be minimized.

The following considerations were taken in to account for the Block Assembly Sequence

- To keep the yard evenly employed an average of 10 units or 3 blocks per week are planned.
- A unit on average consists of a 15 meter by 9 meter assembly.
- A block consists of units joined together transversely. The blocks are no more than 15 meters long and 45 meters wide. The maximum weight of a block is limited to 250 tonnes.
- Some weeks are loaded more heavily during the layout of the machinery rooms.
- As the ship comes to closer completion, the load in units/week starts to drop off.

- A logical sequence for erection is used with sequential blocks laid out in consecutive weeks.
- The ship starts in the middle and works towards the ends.
- Critical long lead time material, identified in the next section, is scheduled for assembly when available.
- As soon as a machinery room is completed, the deck on top of it is assembled to reduce exposure to the weather.
- More complicated sections like the bow are assembled during low throughput weeks.

The block breaks and the erection sequence is shown in Figure A-45.



## Material Procurement

Concurrent to Production Planning, the material needed to build the ship is identified and ordered. Internally generated and vendor provided components should be ordered for Just In Time (JIT) delivery. Material ordered too early results in higher inventory costs, degradation of product due to storage methods and loss of liquidity of shipyard cash flow. Late delivery of material results in disruption to the production plan. Out of sequence work may need to be used to make up for the material shortfalls. Of particular interest is long lead time material like main propulsion engines. The ordering of these items early in the process is critical to reducing cycle times. Keeping a close eye on manufacturers lead times is a prerequisite for efficient insertion into the ship at the correct stage. The items found in Table A-25 represent typical long lead time materials. The manufacturers lead times represent real numbers provided by the vendors for the specialized gear like waterjets. The other values were taken from the LX Generic Build Strategy study.

...

Item Description	MFG Lead Time (Weeks)	Land On Ship (WBD)	Required Order Date (WBD)
Reduction Gears	78	72-67	150
SSGT 2500 kw	72	72-67	145
Reefer Plant	72	78	150
Machinery Control	72	72-67	145
Main Engines LM-6000	72	72-67	145
Water Jets	72	66-64	139
Switchboards	64	72-67	136
Motor Fire Pumps (1000 gpm)	56	78-67	135
Distilling Plant	56	66	123
A/C Unit 200 tonne	56	69	126
Fuel Oil Transfer Pump	52	69-67	122
Seawater Cooling Pump	52	69-67	122
Potable Water Pump	52	69-67	122
JP-5 System Pump	48	57	106
Ventilation Fans	48	65-60	114
Lifeboats and Davits	40	50	91
Lighting and Electric Cables	30	55	86
Sewage Plant	20	80	101
Steel	16	96	113
Deck Machinery	20	72	93
Navigation Gear	12	39	52
Communications	12	39	52

Table A-25 - Long Lead Time Materials and Procurement Schedule

### **Construction Stages**

The stages of construction were identified in Figure A-43. These will be investigated for several shipyards in the next chapter. Most shipyards in this country use a modular method for constructing ships. This tends to minimize the amount of time a ships remains in the construction ways prior to launch. The amount of pre-outfitting a

shipyard accomplishes before launch of the ship is a function of the yard's installed facilities and characteristics.

## **Detailed Design**

The first of the contractor's actions after award of the contract is Detailed Design. The requirements introduced by the customer in the Contract Design are converted into actual working documents and drawings. This process may require a few months for a commercial ship or longer for a complex military ship prior to the start of construction. The Detailed Design provides input for Production Planning, Material Procurement, and Manufacturing. Detailed Design continues as construction starts supporting the downstream phases. Only a small portion of the drawings needed to build the ship are completed when construction of the ship starts. The overlap between phases is very difficult to manage. If changes need to be made for producibility, safety or cost, they should be made as early in Detailed Design as possible.

Detailed Design is the first point where the contractor can make improvements to the product or process. Hopefully, many of the producibility issues were raised in the Contract Design IPT. In Detailed Design, the shipyard uses all of its competitive advantages to produce the ship for less cost while meeting owner requirements. As much effort should be made as possible prior to start of construction to get good ideas from the customer and the production people. As many common components as possible should be used to gain economies of scale in the Fabrication stage. As the design matures,

producibility improvements become more difficult and expensive to accommodate. After a certain point, most producibility items are not worth the interference with the rest of the construction process to be included.

## **Producibility**

Several factors were examined to try to keep the design as producible as possible. A producibility checklist is used to ensure as many good ideas are incorporated into the design at an early stage. The following decisions are made using several sources for guidance.<sup>7475</sup>

- The block breaks take advantage of the maximum size plates that can be delivered over the road.
- Standard plate and shape sizes are used throughout the ship.
- WT or bulb T stiffeners are used instead of W-T.
- Thin plate will be avoided to reduce welding distortion.
- Transom stern is flat with sharp corners instead of curved plates
- The shape of the bow is very simple with limited double curvature.
- The amount of double curved plates on the entire ship is minimized.
- No sheer or camber in the decks.

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<sup>74</sup> Bunch, H.M., (1993) Producibility Check-Off List, Revision 2, October 27, 1993, Department of Naval Architecture and Marine Engineering, University of Michigan.

<sup>75</sup> Brown, A.J. and Barentine, J.B. (1996) The Impact of Producibility on Cost and Performance in Naval Combatant Design, Naval Construction and Engineering Program, Massachusetts Institute of Technology, Cambridge, MA.

- As much flat plate as possible is used. Any additional shaping adds complexity and cost to the project.
- Block Breaks are matched to transverse bulkheads where possible
- Trunks and enclosures are arranged at block divisions
- Common deck heights are used where possible
- The three engine rooms are laid out in identical fashion with the main engines offset to accommodate shafting
- The spaces are arranged to minimize piping and ventilation runs
- Systems are arranged by zones. The habitability spaces are directly on top of each other minimizing redundant piping runs.
- Longitudinal piping and cable boxes are provided to minimize overhead runs.
- Standard outfit packages are used for state rooms and sanitary spaces
- HVAC is run in trunks

Although this list is not complete, significant effort was taken in the conceptual stage to make SOCV a producible ship. Even though the application requires a high performance hull form, good decisions made early in the design can pay off during the construction phase. Additional inputs taken from the SOCV IPT and implemented early in the design can reduce the need for change to the project once fabrication begins. As much information as possible should be taken into account in the early stages. As the process moves into the fabrication stage, most change will be reserved until the next hull. Critical safety and performance change will be allowed only under extreme circumstances.

For SOCV, the total design and engineering hours are estimated to be 250,000 man-hours or 6250 man weeks at 8 hours per day. Ingalls will need to decide whether to absorb this work with their own staff or supplement with a design firm. Ingalls recently finished a redesign for DDG-51 Flight IIA. The only other design work on the horizon is the Arsenal Ship program..

### **Fabrication of Products**

Fabrication begins with the cutting of the first piece of steel. Burn tables are used to produce shapes from steel plates using a variety of cutting techniques. Other plates are pressed or rolled to form the curved sides of the ship. The frames and strakes are formed using I beams or Ts. The small assemblies that will be brought together to form units are either manufactured by the yard or purchased from sub contractors. Accuracy control at this initial stage is very important for the rest of the construction process. It is estimated that only 13% of the man hours required to produce the SOCV will be expended at this stage. It is the most important stage for determining the quality of the end product. Many managers choose to concentrate their efforts on later phases of construction where more man hours and heavy equipment are required. Without a firm handle on product and process control in the fabrication stage, the later phases will experience difficulties. The impact of poor quality in the early stages can be demonstrated with simulation.

The total amount of steel and outfitting throughput for this project is 17,500 tonnes. The net required working area of the assembly shops is approximately 16,571

m<sup>2</sup>. The utilization over the 74 weeks of structural fabrication will be approximately 1.65 tonne/ m<sup>2</sup>/year. This utilization rate can be absorbed using a single shift at Ingalls.

The first ship will be erected in 101 blocks over a period of 58 weeks. In addition, base work in the shipyard chosen will continue. The second SOCV will follow with a six month delay. Each SOCV will require approximately 10 units or 3 blocks per week. The maximum throughput the yard could sustain without large increases in infrastructure will need to be examined. If this load raises the capacity utilization to levels higher than 90%, the schedule may need to be shifted until more room is available in the yard. The 90% capacity utilization limit provides adequate margin for emerging work or other commercial contracts.

Just In Time (JIT) delivery of raw stock and pieces should be arranged with subcontractors. This reduces the amount of work in progress and forces the yard to improve its internal flow of material. Incoming material should be packaged as a unit by the subcontractor in one day equivalents. This reduces the amount of support or “no touch” labor needed by the shipyard to start work each day.

Fabrication is the first stage in which producibility factors are critical. If many of the smallest components of the ship are common, the fabrication process requires less retooling of machines. This will reduce the number of man hours and improve the quality of the products moving through this phase.

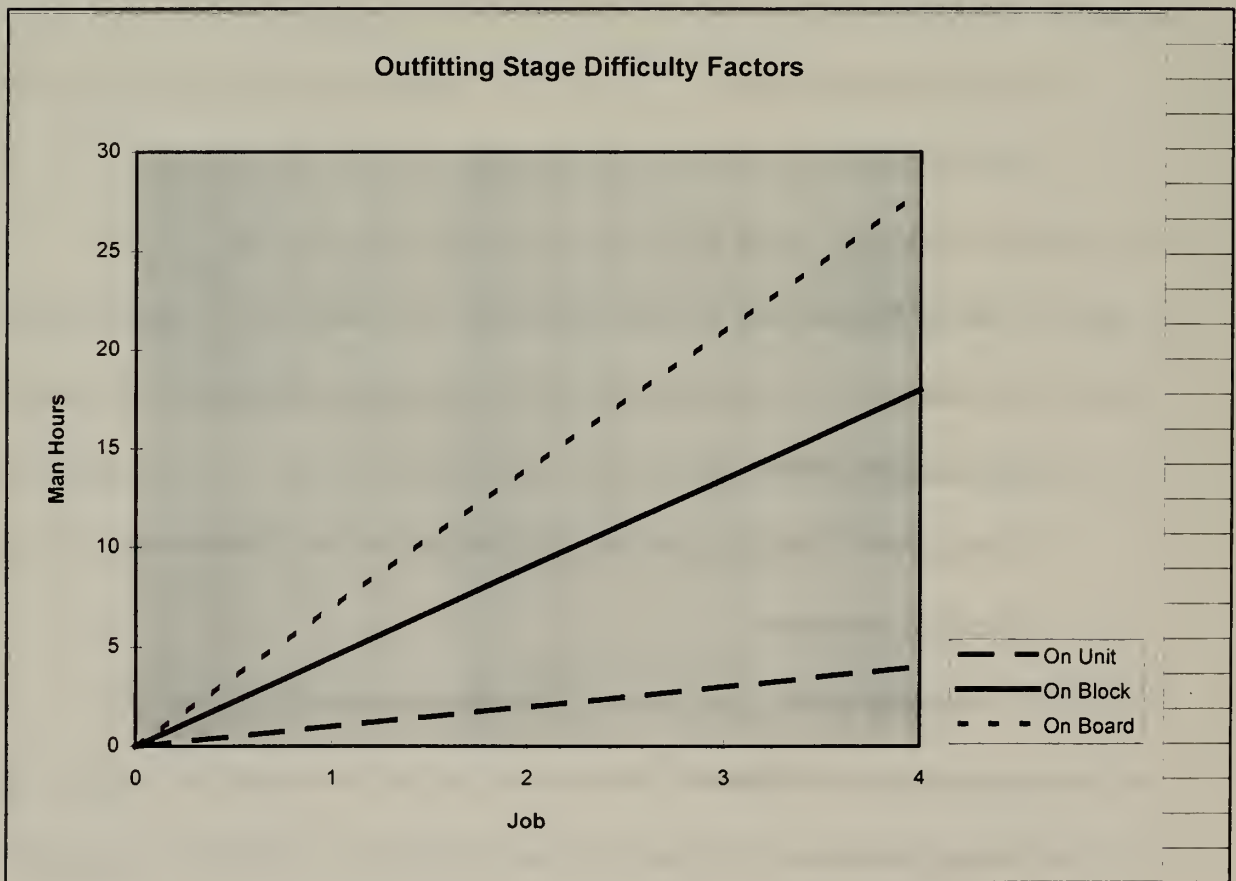
## On Unit

This stage of construction is conducted independent of the hull structure. As much of the fabricated parts, equipment and pipework as possible is assembled in packaged units at the shop level, detached from the structural steel. The different systems of equipment are tested in the shop to prevent costly tear out for faulty equipment later in the outfitting process. All equipment and pipe packaged units receive a final coat of paint prior to installation aboard ship. These measures act to reduce the amount of work that must be done in the constrained environment of the ship. The units that will be installed as separate packages include:

- Fuel Oil Transfer Pump
- A/C Plants
- Vent Fans
- Luke Oil Pumps
- Fire Pumps
- Desalinization Plant
- Refrigeration Plant
- Electrical Generators
- Switchboards
- Main Propulsion Engines
- Control Console
- Exhaust Stacks and Silencers

- Waterjets
- Sea Water Pumps
- Sewage Systems

On Unit Outfitting can be done indoors in a controlled environment allowing high quality and productivity. Figure A-46 provides a look at the change in productivity from one outfitting stage to the next. The units produced in the stage will be introduced to the structural steel support foundations in the next outfitting stage.



## Figure A-46 - Outfitting Productivity<sup>76</sup>

As a result of benchmarking Japanese shipbuilding, one of the practices instituted by several US yards has been to increase the amount of work done On Unit. This pushes much of the labor hours to an earlier stage. It also tends to spread the work being done around the yard. Interference among trades is minimal. All necessary interfaces for services including welding leads, electrical and pneumatic lines are readily available.

In order to be able to invest so much of the total man hours to pre-outfitting, accuracy control must be tight. If a block that has been fully outfitted is determined to be too far out of tolerance, the time and effort invested in pre-outfitting is lost. The responsibility for accuracy control should be on the lowest level, in the shops. If proper tolerance can be measured at this early stage, the rest of the assembly will proceed smoothly. If the work force at the lowest level is not held responsible for their products, rework will be required to correct the deficiencies. Quality deficiencies will be traced to their source. The faulty equipment will be returned to the error originating station and not passed on down the line for rework.

### **On Block**

The assembly of outfit components onto structural subassembly or blocks prior to erection is called On Block outfitting. In this stage the packaged systems are placed onto structural steel. In many shipyards, the assembly of structural steel and outfitting are

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<sup>76</sup>Lamb, T., (February 1994), Build Strategy Development, The National Shipbuilding Research Program, Carderock Division, Naval Surface Warfare Center, Bethesda, Maryland

tracked separately. The functions are basically the same and should be accounted for with the same system. Smaller components are brought together to form larger blocks. As much of the piping, ventilation, lighting and machinery as possible is installed prior to erection on the ways. A critical component of this stage is the decision to conduct a final blast and paint. Proper preparation of material coatings and use of weld through primer could eliminate the need for a final blast and paint at this stage. This could reduce the amount of interference experienced in this phase. World class shipbuilders find it unnecessary to conduct a final blast and paint. Half the US shipyards visited use final blast and paint while the other half does not. The quality of the yards that do not conduct a final blast and paint in this country is below those that take time to add this step to their processes. Both hot and cold work is done at this stage. Hot work consists of welding structural steel units together into blocks. Cold work consists of attaching On Units packages which may be bolted to the deck.

Local cable runs and joiner doors are installed. Initial paint out, pipe lagging and bulkhead insulation are all be applied in this stage. The limit to how much can be done during On Unit and On Block Outfitting is the capacity of the overhead crane or other block transfer equipment. For this ship in the selected yard, the limit for pre-outfitting is set at 300 tons/block.

## **On Board**

On Board Construction consists of the final erection of the ship and additional outfitting work not able to be accomplished On Block. This is the most difficult

outfitting stage in which to work. Many interferences and constraints are experienced at this stage. Structural bulkheads and overhead decks tend to limit access to compartments of interest. Although the construction area will normally be out of the weather, many other trades compete for access to different spaces. As little work as possible should be scheduled for On Board outfitting.

As the blocks are erected and welded together in accordance with the Assembly Plan, other considerations need to be taken into account. Main machinery equipment must be loaded when the structural decks are in place. Inter-block systems, like cables and piping, need to be run and connected. When all of these functions occur simultaneously, the result is a very busy and crowded work space.

After the ship is launched the rest of the On Board outfitting is accomplished. This includes final alignment of propulsion shafting and bearings, final paint and preservation, and other cosmetic items not on the critical path prior to sea trials. This stage also signals the transition of the ship from the shipyard to the Navy. An extensive compartment close out list is used to correct any remaining discrepancies. Light off of main and auxiliary machinery and extensive testing occurs during this period.

## **Productivity Goals**

The direct productivity goal for this ship is set at 80 man-hours/tonne steel. This is the better than the national average productivity for a ship of this type and size of about 110 mh/tonne. Another measure of productivity used internationally is man-

hours/compensated gross ton (CGT). The vessel gross tonnage is 17,500 tonnes. The associated gross tonnage factor is 0.95 yielding a compensated gross tonnage of 15,650 tonnes. The total man hours required to produce this ship is 2,052,000 hours. For comparison purposes, good European yards use 45 man hours/CGT. Japanese yards are using 29 man hours/CGT.<sup>77</sup> The productivity overseas is clearly higher than what can be accomplished domestically. For US yards to compete internationally, this is the place where improvements must be made.

## Summary

The SOCV Build Strategy is used establish many initial values and set the work profile for the Ship Production Model in Chapter 5. The Build Strategy defines what will be produced. A summary of the important outputs from the Build Strategy development process are provided below in Table A-26.

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<sup>77</sup> Frankel, E.G. (1990) The Path to US Shipbuilding Excellence - Remaking the US into a World Class Competitive Shipbuilding Nation, NSRP 1990 Ship Production Symposium, August 21-24, 1990, Milwaukee, WI.

Parameter	Value
Number of Blocks	101
Design Schedule (wks)	112
Keel to Launch (wks)	58
Design Staff	200
Structural Staff	850
Productivity Goal (mh/CGT)	80
Engineering Hours	250,000
Production Hours	2,052,000
Fabrication Work Orders	41040
Assembly Work Orders	61560
On Unit (20% of Assembly w/o)	12312
On Block (35% of Assembly w/o)	21546
On Board (45% of Assembly w/o)	27702
Overhead (% of direct costs)	33.3
Project Deadline (wks)	150 wks
Over Run Penalties (\$/wk)	350,000

**Table A-26 - Dynamic Model Inputs**

In Chapter 3 the attributes of the shipyard selected to produce the SOCV were discussed. Additional strategic variables which describe the shipyard are identified. The constraints to production are discussed and quantified. The management policies needed to run the shipyard are discussed. Additional characteristics of the workforce are investigated.

## Appendix B - Model Equations

All of the equations used to simulate the Ship Production Model are included here. Some of the structures were taken from the Molecules of Structure created by Jim Hines. Other formulations were borrowed from the work in the Vensim users manual. Most of the equations were built based on the yard observations, Ken Cooper's paper, and David Ford's work. These references can be found in the reference sheet.

\*\*\*\*\*

### .Review

\*\*\*\*\*~

This work represents a multiphase project model of the shipbuilding process. The phases include: design, fabrication, on unit outfitting, on block outfitting and on board erection. These phases demonstrate prerequisite dependency and work quality flow through. Several constraints to work flow are include: labor, material, work space, and lift capacity

|

\*\*\*\*\*

### .Control

\*\*\*\*\*~

Control parameters for the model.

|

FINAL TIME = IF THEN ELSE(Project Compl Time > 0,  
    QUANTUM(Project Compl Time+15\*UNIT TIME,10\*UNIT TIME),  
    MAX FINAL TIME)

~ week

~ The time at which the simulation ends.

|

INITIAL TIME = INITIAL(VMIN(INIT SCHED START TIME[phase!]))

~ week

~ The initial time for the simulation

|

MAX FINAL TIME = 800

~ week

~ The maximum number of weeks for simulation even when the project is not finished.

|

SAVEPER = 1

~ week

~ The frequency with which data is stored.

|

TIME STEP = 1

~ week

~ The solution interval for simulating the model.

|

UNIT TIME = 4

~ week

~ Unit time used for dimensional consistency

|

\*\*\*\*\*

.Subscript

\*\*\*\*\*~

A list of subscripts used by the model.

|

downstream <-> phase

~ Nil

~ Downstream phases.

|

prereq <-> phase

~ Nil

~ The prerequisites for doing phase (other phases)

|

phase : DESIGN, FABRICATION, ONUNIT, ONBLOCK, ONBOARD

~ Nil

~ The phases that make up the construction process.

|

\*\*\*\*\*

.Activity

\*\*\*\*\*~

|

Project is Done = Phase is Done[ONBOARD]

~ dmn1

~ Flag to indicate that the project is completed.After On Board outfitting is done,

~:SUPPLEMENTARY

|

Phase is Active[phase] = IF THEN ELSE(Phase is Started[phase] :AND: :NOT:

Phase is Done[phase],1,0)

~ dmn1

~ Flag to show which phases are active.

|

Phase is Done[phase] = IF THEN ELSE(Reported Fraction Complete[phase] > Required  
Fraction Complete[phase],1,0)

~ dmn1

~ Flag to indicate if the phase is finished.

|

Phase is Started[phase] = IF THEN ELSE(Time >= Sched Start Time[phase],1,0)

~ dmn1

~ Flag to indicate if a phase has been started.

|

\*\*\*\*\*

.Definition

\*\*\*\*\*~

The size, scheduling, work requirements and patterns for the project.

|

INIT SCHED START TIME[phase] = 0,54,54,60,90

~ week

~ The week at which each phase of the project starts.

|

Initial Schedule Completion Time[phase] = 102,102,88,102,128

~ week

~ The initial scheduled completion time for each phase.

|

Prerequisite Dependency[DESIGN,prereq] = 0,0,0,0,0 ~|

Prerequisite Dependency[FABRICATION,prereq] = 1,0,0,0,0 ~|

Prerequisite Dependency[ONUNIT,prereq] = 1,1,0,0,0 ~|

Prerequisite Dependency[ONBLOCK,prereq] = 1,1,1,0,0 ~|

Prerequisite Dependency[ONBOARD,prereq] = 1,1,1,1,0

~ dmn1

~ Switches showing which phases depend on which for completion.

|

Prerequisite Required Fraction Complete[phase] = 0.3

~ dmn1

~ The required completeness on prerequisite work before a phase can be started. Could be by [phase,prereq].

|

Required Fraction Complete[phase] = 0.98

~ dmn1

~ The fraction of a phase that needs to be complete before the phase can be stopped.

|

Phase Definition[phase] = 12500,39726,14123,26300,21530

~ work orders

~ The definition of how much work needs to be done in each phase in equivalent units. For design, the units are engineering man hours. For Fabrication, the units are work orders which represent 20 hours of production labor. For On Unit, the units are products which represent 100 work orders per product. For On Block, the units are blocks which represent 3-5 products per block. For On Board, the units are erection man hours. All values are converted to work orders for consistency.

|

Planned Fraction Schedule Passed[phase] = IF THEN ELSE (Time + Time to Adjust Labor[phase] > Sched Start Time [phase], IF THEN ELSE (Time + Time to Adjust Labor[phase] < Sched Comp Time[phase], (Time + Time to Adjust Labor[phase] - Sched Start Time[phase]) / (Sched Comp Time[phase] - Sched Start Time[phase]), 1), 0)

~ dmn1

~ The fraction of the schedule that has passed. Adjusts itself in response to schedule slippages.

|

Planned Relative Effort Intensity[phase] = XIDZ(Planned Work Profile[phase] (Planned Fraction Schedule Passed[phase]) \* (1 - Planned Fraction Schedule Passed[phase]), LOOKUP AREA(Planned Work Profile[phase], Planned Fraction Schedule Passed[phase], 1), 1)

~ dmn1

~ Relative effort intensity as determined by the planned profile of effort - for the fraction of time in a phase left remaining.

Planned Work Profile[DESIGN] ((0,0)-(1,1),(0,0),(0.2,1),(0.8,1),(1,0) ) ~|  
 Planned Work Profile[FABRICATION] ((0,0),(0.2,1),(0.8,1),(1,0) ) ~|  
 Planned Work Profile[ONUNIT] ((0,0),(0.2,1),(0.8,1),(1,0)) ~|  
 Planned Work Profile[ONBLOCK] ((0,0),(0.2,1),(0.8,1),(1,0)) ~|  
 Planned Work Profile[ONBOARD] ((0,0),(0.2,1),(0.8,1),(1,0))

~ dmn1

~ The planned profile of effort for each phase - shows ramp up and ramp down of the planned effort.

Planned Work Remaining[phase] = ACTIVE INITIAL(MAX(0,Reported Work Remaining[phase] -

Project Labor[phase]\*Normal Productivity[phase]\*Time to Adjust Labor[phase] \*  
 XIDZ({planned work profile[phase](fraction schedule passed[phase]) +}  
 Planned Work Profile[phase](Planned Fraction Schedule Passed[phase]),  
 Planned Work Profile[phase](Fraction Schedule Passed[phase]),1)),  
 Reported Work Remaining[phase])

~ unit

~ The planned amount of work remaining as used in hiring decisions.

Relative Effort Intensity[phase] = XIDZ(Planned Work Profile[phase]  
 (Fraction Schedule Passed[phase]) \* (1 - Fraction Schedule Passed[phase]),  
 LOOKUP AREA(Planned Work Profile[phase],Fraction Schedule  
 Passed[phase],1),1)

~ dmn1

~ Relative effort intensity as determined by the planned profile of effort  
 - for the fraction of time in a phase left remaining.

Work Remaining[phase] = INTEG(Discovering Rework[phase]-Gross Completion  
 Rate[phase],Phase Definition  
 [phase])

~ units

~ The amount of work remaining to be done in each phase

Time to Schedule Change = 4

~ weeks

~ |

Added Scope[phase] = 0,0,0,0,0

~ workorders

~ Additional Scope of work added by the Navy at some prescribed date after the project has started.

|

Order Book = 3+STEP(150,-1)+STEP(250,-2)

~ Ships

~ The amount of work the shipyard has under contract

|

\*\*\*\*\*

.Schedule

\*\*\*\*\*~

Items relating to schedule and triggers for schedule slippage

|

Project Compl Time = INTEG(IF THEN ELSE(Project Compl Time = 0:AND:  
Project is Done,Time/TIME STEP,0),0)

~ week

~ The time at which the project was completed.

|

Expected Completion Time[phase] = IF THEN ELSE(Phase is Active[phase],  
Time + Expected Time Remaining[phase],Sched Comp Time[phase])

~ week

~ The expected time at which the phase will complete.

|

Fraction Schedule Passed[phase] = IF THEN ELSE (Time > Sched Start Time[phase],  
IF THEN ELSE(Time < Sched Comp Time[phase],(Time - Sched Start  
Time[phase])/

(Sched Comp Time[phase] - Sched Start Time[phase]),1),0)

~ dmnl

~ The fraction of the schedule that has passed. Adjusts itself in response  
to schedule slippage.

|

Initial Phase Length[phase] = INITIAL(Initial Schedule Completion Time[phase]  
- INIT SCHED START TIME[phase])

~ week

~ The initial length of the phase in weeks.

|

Prerequisites in Place[phase,prereq] = IF THEN ELSE((Prerequisite  
Dependency[phase,prereq] = 0):OR:Reported Fraction Complete[prereq] > Prerequisite  
Required Fraction Complete[phase],1,0)

~ dmn1

~ Switch to indicate if all prerequisites are in place.

|

Sched Comp Time[phase] = INTEG(sched comp time slip[phase],Initial Schedule  
Completion Time[phase])

~ week

~ The scheduled completion time.

|

sched comp time slip[phase] = Scheduled Start Slip Time[phase] +

IF THEN ELSE(Phase is Active[phase] :AND:

Schedule Time Remaining[phase] < SLIP ZONE :AND:

Expected Time Remaining[phase] -

Schedule Time Remaining[phase] > SLIP TRIGGER,

SLIP INCREMENT/TIME STEP,0)

~ week/week

~ The slippage in the scheduled completion time.

|

Sched Start Time[phase] = INTEG(Scheduled Start Slip Time[phase],INIT SCHED  
START TIME[phase])

~ week

~ The scheduled start time.

|

Scheduled Start Slip Time[phase] = IF THEN ELSE(Phase is Active[phase] :OR:

VMIN(Prerequisites in Place[phase,prereq!]) > 0 :OR:

(Time + TIME STEP < Sched Start Time[phase]) ,

0,Start Slip Trigger Increment/TIME STEP)

~ week/week

~ The amount of time the scheduled start time slips in response to slippage  
in prerequisite phases.

|

Schedule Time Remaining[phase] = MAX(0,Sched Comp Time[phase] - Time)

~ week

~ The amount of time remaining in the schedule.

|

SLIP INCREMENT = 4

~ week

~ The amount of time the schedule is slipped, if it needs slipping.

|

SLIP TRIGGER = 8

~ week

~ The amount of time behind schedule at which the completion date will be slipped.

|

SLIP ZONE = 12

~ week

~ The distance from the end of a project at which schedule slippage becomes an alternative.

|

Start Slip Trigger Increment = 0.5

~ week

~ The slip increment for starting a phase up if things are behind schedule.

|

\*\*\*\*\*

.Workforce

\*\*\*\*\*~

Net Project Labor Adjustment[phase] = MIN(Maximum Weekly Labor Adjustment[phase], (Desired Labor[phase] - Project Labor[phase])/Time to Adjust Labor[phase])

~ person/week

~ The net adjustment of labor (additions or reductions. Notice this is capped.)

|

Desired Labor[phase] = MIN(Maximum Labor[phase], IF THEN ELSE(Time + Time to Adjust Labor[phase] >= Sched Start Time[phase] :AND: :NOT:Phase is Done[phase],  
XIDZ((Planned Work Remaining[phase] / Normal Productivity[phase])  
\*Planned Relative Effort Intensity[phase], Schedule Time Remaining  
[phase], Maximum Labor[phase]), 0))

~ person

~ The amount of labor it is management would like to have.

|

Project Labor[phase] = INTEG(Net Project Labor Adjustment[phase],Desired Labor[phase])

~ person

~ The number of people of a given skill on a given phase.

|

Maximum Weekly Labor Adjustment[phase] = 10,100,50,50,50

~ person/week

~ The maximum rate at which labor can be adjusted for a phase.

|

Time to Adjust Labor[phase] = 2,2,3,3,4

~ week

~ The amount of time required to adjust labor to target values.

|

Maximum Labor[phase] = 200,850,850,850,850

~ person

~ The maximum labor associated with each phase of work

|

Attrition = Veteran Workforce\*0.002

~ people/week

~ The normal attrition rate due to retiring leaving the industry.

|

Available Workforce[phase] = INTEG(-Net Project Labor Adjustment[phase],Veteran Workforce-Base Work Required Labor)

~ person

~ |

Total Required Labor = SUM(Desired Labor[phase!])+Base Work Required Labor

~ people

~ total number of people required to fill needs of shipyard

|

Trainees = INTEG(New Hires-Training,0)

~ person

~ Number of new trainees in the shipyard

|

Hiring Time = 4

~ weeks

~ The amount of time required to hire new labor

|

Layoffs = IF THEN ELSE(Order Book<2,Veteran Workforce-Total Required Labor,0)  
~ person  
~ The amount of people layed off in a week if order book drops below two ships  
|

New Hires = IF THEN ELSE(Veteran Workforce>Total Required Labor,0,(Total  
Required Labor-Veteran Workforce)/Hiring Time)  
~ person/week  
~ The amount of people required to fulfill the needs of the shipyard  
|

Training Time = 36  
~ weeks  
~ The amount of time it takes to train a shipyard worker.  
May be greater for some trades.  
|

Shipyard Workforce = Trainees+Veteran Workforce  
~ person  
~ The total number of people working in the yard  
|

Veteran Workforce = INTEG(Training-Attrition-Layoffs,11000)  
~ person  
~ The amount of people working in the yard  
|

Training = Trainees/Training Time  
~ person/week  
~ The amount of new trainees fully qualified to work on ships produced per week  
|

Base Work Required Labor = 8000  
~ person  
~ |

\*\*\*\*\*

#### .Constraints

\*\*\*\*\*~

The infrastructure constraints to the system. These should not be allowed to control the destiny of the company. They should be identified and dealt with accordingly. Knowing that a constraint exists acts to provide a demotivating factor for improvements. If we do better here,we still have to take care of Blast and Paint. Blast and Paint has been broken for years so what will change?

Blast and Paint Area = 6

|

Infrastructure Constraints to Production[DESIGN] = Engineering Capacity ~|

Infrastructure Constraints to Production[FABRICATION] = Fabrication Capacity ~|

Infrastructure Constraints to Production[ONUNIT] = On Unit Capacity ~|

Infrastructure Constraints to Production[ONBLOCK] = MIN(On Block Capacity,Blast and Paint Capacity) ~|

Infrastructure Constraints to Production[ONBOARD] = MIN(Crane Capacity,Erection Site Capacity)

~ work orders/week

~ Represents the choke point of the installed infrastructure

|

Blast and Paint Capacity = Blast and Paint Area\*BP Converter

~

~

|

BP Converter = 400

~ work order/block

~ Converts blast and paint capacity to products

|

Crane Capacity = Crane Converter\*Cranes

~ work orders/week

~ The total amount of work that can be moved per week by crane

|

Crane Converter = 25

~ work orders/lift

~ Total number of products that can be supported per lift. Each product requires a lift. Each Block requires three lifts. Therefore each lift represents one fourth of the required amount per product.

|

Cranes = 500

~ lift/week

~ Crane capacity in terms of lifts available per week. Average of the time it takes to accomplish all lifts in the yard.

|

Design Converter = 10

~ work orders/drawing

~ The total number of work orders that can be supported by each design

|

Work Stations = 100

~ drawing/week

~ Total number of drawings per week able to be supported by CAD hardware

|

Engineering Capacity = Design Converter\*Work Stations

~ work order/week

~ Number of work orders capable of being supported by current hardware per week

|

Fabrication Capacity = Fabrication Equipment

~ work order/week

~ Total number of products that can be supported by installed fabrication equipment per week

|

Fabrication Equipment = 1500

~ work order/week

~ The amount of work orders the fabrication equipment can support per week

|

On Block Converter = 400

~ work orders/block

~ The number of products that make up a block

|

On Block Area = 10

~ Blocks/week

~ The amount of blocks that can be pushed through the On Block area per week

|

On Block Capacity = On Block Converter\*On Block Area

~ work order/week

~ The amount of products that can be supported by the On Block facilities per week

|

On Unit Area = 16

~ product/week

~ The constraint for the On Unit area

|

On Unit Capacity = On Unit Area\*On Unit Converter

~ work order/week  
 ~ Throughput measured in work orders per week the infrastructure for On Unit Outfitting can support  
 |

On Unit Converter = 100  
 ~ work order/product  
 ~ The total amount of work orders needed for each product  
 |

Erection Site Capacity = Erection Site Converter\*Erection Sites  
 ~ work orders/week  
 ~ The amount of work orders/week the building ways at the yard can support can support  
 |

Erection Site Converter = 4000  
 ~ work orders/Site  
 ~ The amount of work orders possible for each building site  
 |

Erection Sites = 2  
 ~ sites  
 ~ The number of sites capable of erecting a ship  
 |

\*\*\*\*\*  
 .Productivity  
 \*\*\*\*\*~

The total amount of work people get done, and are able to get done.  
 |

Normal Productivity[phase] = 2,2,2,1.5,1  
 ~ work orders/person/week  
 ~ The normal amount of work that is done in the absence of any effects on productivity. Identifies the choke points in the process.  
 |

Avg Overtime Frac[phase] = INTEG((Overtime Fraction[phase] - Avg Overtime Frac[phase])/  
 Time to Average Overtime,1)  
 ~ dmn1  
 ~ The average overtime fraction used as a measure of fatigue.  
 |

Effect Fatigue Prod[phase] = TABLE EFF FATIGUE PROD(Avg Overtime Frac[phase])  
 ~ dmn1  
 ~ The effect of fatigue on productivity.  
 |

Effect of Morale on Prod[phase] = TABLE EFF MORALE PROD((Expected Completion Time[phase]  
 - Initial Schedule Completion Time[phase])/Initial Phase Length[phase])  
 ~ dmn1  
 ~ The effect of morale on productivity  
 |

Effect Prereq Readiness Prod[phase,prereq] =  
 IF THEN ELSE(Prerequisite Dependency[phase,prereq],  
 IF THEN ELSE(Phase is Done[prereq],  
 1,PREREQ EFF SPEED LOOKUP(Reported Fraction Complete[phase])),1)  
 ~ dmn1  
 ~ The effect of prerequisite readiness on work speed.  
 |

Effect Sched Press Prod[phase] = TABLE EFF SCHED PRESS PROD(MIN(5,  
 XIDZ(Expected Time Remaining[phase],Schedule Time Remaining[phase],5)))  
 ~ dmn1  
 ~ The effect of schedule pressure on gross productivity.  
 |

Gross Productivity[phase] = Normal Productivity[phase] \*  
 Effect of Morale on Prod[phase] \*  
 Effect Fatigue Prod[phase] \*  
 Effect Sched Press Prod[phase] \*  
 PROD(Effect Prereq Readiness Prod[phase,prereq!])  
 \* (1 + (RANDOM 0 1() - 0.5) \* PRODUCTIVITY NOISE)  
 ~ work order/person/week  
 ~ The gross amount that people can get done in an hour neglecting  
 any quality or potential rework measures.  
 |

PREREQ EFF SPEED LOOKUP((0,1),(0.5,1),(1,0))  
 ~ dmn1  
 ~ Table relating the fraction complete of a phase to  
 effect on work speed of prerequisites that are not  
 yet completely finished.  
 |

PRODUCTIVITY NOISE = 0

~ dmn1

~ The noise in productivity.

|

TABLE EFF FATIGUE PROD  $[(0,0.6)-(2,1)],(0.5,1),(1,1),(1.1,0.95)$   
 $,(1.2,0.9),(1.3,0.85),(1.4,0.8),(1.5,0.7)$

~ dmn1

~ Table showing the effect of fatigue (average overtime) on  
productivity.

|

TABLE EFF MORALE PROD  $(-1,-0.5,0,0.5,1,1.5,2,4,2,1,0.85,0.75,0.7,0.65)$

~ dmn1

~ The table describing the effect of morale on productivity.

|

TABLE EFF SCHED PRESS PROD  $[(0,0.8)-(20,2)],(0,1),(1,1),(2.93814,1.13947)$   
 $,(4.84536,1.22632),(6.59794,1.24211),(10,1.25)$

~ dmn1

~ Table showing the effect of schedule pressure on productivity.

|

Time to Average Overtime = 8

~ weeks

~ The time taken to formulate the impact of average overtime in determining its  
impact on fatigue.

|

\*\*\*\*\*

.Quality

\*\*\*\*\*~

Equations describing quality and its determinants.

|

Normal Quality[phase] = 0.85

~ dmn1

~ The normal quality of work done when no factors affecting quality are  
deteriorating performance.

|

Effect Fatigue Qual[phase] = TABLE EFF FATIGUE QUAL(Avg Overtime Frac[phase])

~ dmn1

~ The effect of fatigue on quality.

|

Effect Morale Qual[phase] = TABLE EFF MORALE QUAL((Expected Completion Time[phase]

- Initial Schedule Completion Time[phase])/Initial Phase Length[phase])

~ dmnl

~ The effect of morale on quality

|

Effect Prereq Qual Qual[phase,prereq] = IF THEN ELSE(Prerequisite Dependency[phase,prereq],

XIDZ(Work Completed Correctly[prereq],Reported Work Complete[prereq],1),1)

~ dmnl

~ The effect of prerequisite quality on quality. Quality is not a measurable quantity in the

shipyard. Must be determined by internal factors and acceptance by the customer.

|

Effect Schedule Press Qual[phase] = IF THEN ELSE(Phase is Active[phase],

TABLE EFF SCHED PRESS QUAL(XIDZ(Expected Time Remaining[phase], Schedule Time Remaining[phase],5)),1)

~ dmnl

~ The effect of schedule pressure on gross quality.

|

QUALITY NOISE = 0

~ dmnl

~ Noise output as a result of quality variation.

|

TABLE EFF FATIGUE QUAL ( 0.5,1,1.1,1.2,1.3,1.4,1.5,1,1,0.95,0.9,0.85,0.8,0.7)

~ dmnl

~ Table showing the effect of fatigue (average overtime)on quality.

|

TABLE EFF MORALE QUAL (-1,-0.5,0,0.5,1,1.5,2,1,1,1,0.95,0.9,0.85,0.85)

~ dmnl

~ The table describing the effect of morale on quality..

|

TABLE EFF SCHED PRESS QUAL (0,1,2,5,10,1,1,0.95,0.9,0.8)

~ dmnl

~ Table showing the effect of schedule pressure on quality.

|

Work Quality[phase] = Normal Quality[phase] \*  
 Effect Morale Qual[phase] \*  
 Effect Fatigue Qual[phase] \*  
 Effect Schedule Press Qual[phase] \*  
 PROD(Effect Prereq Qual Qual[phase,prereq!]) \*  
 (1 - RANDOM 0 1()) \* QUALITY NOISE)

~ dmnl

~ The quality of work being done by people.

|

\*\*\*\*\*

.Progress

\*\*\*\*\*~

Work that is actually getting done.

|

Discovering Rework[phase] = MAX(0,MIN(Undiscovered Rework[phase]/  
 TIME STEP,Undiscovered Rework[phase]/Rework Discovery Time[phase] +  
 SUM(Downstream Rework Discovery[downstream!,phase]))) + Added  
 Scope[phase]/Time to Schedule Change

~ work order/week

~ The rate of discovery of rework and new work due to change

|

Possible Labor Completion Rate[phase] =Project Labor[phase]\*Gross  
 Productivity[phase]\*Overtime Fraction  
 [phase]

~ work order/week

~ The amount of work that can be done as a factor of Labor constraints

|

Gross Completion Rate[phase] =IF THEN ELSE(Work  
 Remaining[phase]>0,MIN(Infrastructure Constraints to Production  
 [phase],Possible Labor Completion Rate[phase]),0)

~ work order/week

~ The rate at which both correct and flawed work is being  
 completed based on labor and infrastructure constraints.

|

Undiscovered Rework[phase] = INTEG(Gross Completion Rate[phase] \* (1-Work Quality  
[phase]) - Discovering Rework[phase],0)

~ work orders

~ The amount of work that is done incorrectly and requires correction, but has not yet been detected.

|

Work Completed Correctly[phase] = INTEG(Gross Completion Rate[phase] \* Work Quality  
[phase],0)

~ work orders

~ The amount of work that is completed correctly.

|

Downstream Rework Discovery[downstream,phase] = IF THEN ELSE(  
Phase is Active[downstream] :AND:  
Prerequisite Dependency[downstream,phase], Undiscovered Rework[phase]/  
Prerequisite Rework Discovery Time[downstream,phase],0)

~ work order/week

~ The discovery of errors in downstream phases.

|

Expected Time Remaining[phase] = IF THEN ELSE(Phase is Started[phase],  
IF THEN ELSE(Phase is Done[phase],  
0,MIN(2\*Initial Phase Length[phase],  
XIDZ(Reported Work Remaining[phase],  
Normal Productivity[phase] \*  
Expected Effective Labor[phase],  
2\*Initial Phase Length[phase]))),  
Initial Phase Length[phase])

~ week

~ The expected time remaining to the completion of the phase.

|

Expected Effective Labor[phase] = XIDZ(Project Labor[phase],  
Relative Effort Intensity[phase],  
Reported Work Remaining[phase]/Normal Productivity[phase]/  
Initial Phase Length[phase])

~ person

~ The expected effective workforce

|

Normal Rework Discovery Time[phase] = 6,5,3,3,2

~ week  
 ~ The normal time it takes to discover errors.  
 |

Overtime Fraction[phase] = TABLE OVERTIME FRAC(XIDZ(Expected Time Remaining[phase],Schedule Time Remaining[phase],1))  
 ~ dmn1  
 ~ The amount of overtime being worked.  
 |

Prerequisite Rework Discovery Time[DESIGN,phase] = 6 ~|  
 Prerequisite Rework Discovery Time[FABRICATION,phase] = 4 ~|  
 Prerequisite Rework Discovery Time[ONUNIT,phase] = 3 ~|  
 Prerequisite Rework Discovery Time[ONBLOCK,phase] = 3 ~|  
 Prerequisite Rework Discovery Time[ONBOARD,phase] = 1  
 ~ week  
 ~ The time to discover errors in prerequisite work.  
 |

Reported Fraction Complete[phase] = Reported Work Complete[phase]/Phase Definition[phase]  
 ~ dmn1  
 ~ The fraction of work that is reported to be complete.  
 |

Reported Work Remaining[phase] = MAX(0,Phase Definition[phase] - Reported Work Complete[phase])  
 ~ work orders  
 ~ The reported amount of work remaining.  
 |

Reported Work Complete[phase] = Work Completed Correctly[phase] + Undiscovered Rework[phase]  
 ~ work orders  
 ~ The amount of work that is reported to be complete.  
 |

..  
 Rework Discovery Time[phase] = Normal Rework Discovery Time[phase] \* TABLE EFF FRAC COMP[phase](Reported Fraction Complete[phase])  
 ~ week  
 ~ The time required to detect existing problems.  
 |

TABLE EFF FRAC COMP[DESIGN] ((0,1),(0.5,1),(0.6,0.8),(0.7,0.6), (0.8,0.4),(1,0.2))

~~|

TABLE EFF FRAC COMP[FABRICATION] ((0,1),(0.5,1),(0.6,0.8),(0.7,0.6),

(0.8,0.4),(1,0.2)) ~~|

TABLE EFF FRAC COMP[ONUNIT] ((0,1),(0.5,0.9),(0.75,0.4),

(1,0.2)) ~~|

TABLE EFF FRAC COMP[ONBLOCK] ((0,1),(0.5,0.9),(0.75,0.4), (1,0.2)) ~~|

TABLE EFF FRAC COMP[ONBOARD] ((0,1),(0.5,0.9),(0.75,0.4),(1,0.1))

~ dmn1

~ Table showing the effect of the fraction complete on the speed with which errors are discovered.

|

TABLE OVERTIME FRAC (([-0.2,0)-(4,2)],(-0.1,0),(0,0.3),(1,1)

, (1.2,1.1),(1.5,1.2),(2,1.3),(3,1.3) )

~ dmn1

~ Table showing the overtime fraction as a function of behind schedule.

|

\*\*\*\*\*

.Financial

\*\*\*\*\*~

Financial performance of the project

|

Weekly Overhead Cost[phase] = Weekly Phase Labor Cost[phase]/3

~ dollars

~ The cost of maintaining the shipyard features and shipyard personnel

|

Weekly Costs[phase] = Weekly Phase Labor Cost[phase]+

Weekly Overhead Cost[phase]

~ dollars/week

~ The ongoing cost of a phase including labor and materials.

|

Weekly Phase Labor Cost[phase] = Project Labor[phase]\*.Wage Rate

~ dollars/week

~ The cost of labor for each particular phase.

|

Total Cumulative Project Cost = SUM(Cumulative Phase Cost[phase!])+Overrun Charge

~ dollars

~ The total cumulative cost of running the project

~:SUPPLEMENTARY

|

Cumulative Phase Cost[phase] = INTEG(Weekly Costs[phase],0)

~ dollars

~ The cumulative cost of each phase

|

Total Weekly Cost = SUM(Weekly Costs[phase!])

~ dollar/week

~ The total weekly cost of running the project

~:SUPPLEMENTARY

|

Overrun Charge = IF THEN ELSE(Project is Done,0,MAX(0,Overrun Charge Rate\*(Time-(10+Initial Schedule Completion Time[ONBOARD]))))

~ dollars

~ The over run charges for a late project.

|

Overrun Charge Rate = 350000

~ dollars/week

~ The penalty assessed on project lateness per week. Kicks in after a 10 day grace period

|

Wage Rate =1600

~ dollars/person/week

~ The cost of maintaining the average worker at the yard in terms of base pay and benefits.

|

..

## Appendix C - Glossary of Terms

3-D Product Model - Captures all of the information needed to describe a ship

ABS - American Bureau of Ships

Anchor Windlass - Used to raise and lower the anchor and chain

Arsenal Ship - Large missile carrying ship with over 500 vertical launch cells

ATC - Affordability Through Commonality Program

BATHMAX 1500 - Teaming effort of Kvearna Masa and Bath Iron Works for fast container ship - 1500 TEU capacity

BIW - Bath Iron Works

Block - Construction section of the ship - max 250 tons

Burn Tables - Machines in the Fabrication facility where plates are cut into shapes. The processes used are different for each shipyard.

Crash Astern Test - While going max speed forward, reverse the engines to max reverse to see how long it takes to stop the ship.

CATEA - Visualization Software used by Bath and Electric Boat. Also used by Boeing on the 777 program

Computer Vision - 3-D CAD Package

CONUS - Continental United States

COTS - Commercial Off The Shelf

CPM - Critical Path Method

CVX - Next generation aircraft carrier

Davits - Used to launch and recover small boats

DDG-51 Flight IIA - Added helicopter support and lengthened base design

DMRS - Defense Mobility Requirements Study

DWL - Designed Water Line

DYNAMO - System Dynamics modeling software

ECP - Engineering Change Proposal

Erection Site - The place where the ship is put together. This could be a dry-dock, a shipbuilding ways, or on a land level translator depending on the shipyard.

FASTSHIP Atlantic - Semi Planing Hull proposed by Thornycraft and Giles with 1500 TEU capacity

Frames

FTV - Future Technology Variant of Mid Term Sealift Technology Development Program

HVAC - Heating, Ventilation and Air Conditioning

IHI - Ishikawajima-Harima Heavy Industries ..

ISO 9000

JIT - Just In Time

Lagging - pipe insulation

Light Off - Start an engine or boiler

LCC - Life Cycle Cost

SOCV - Sealift Option, Commercially Viable - A new approach to providing the surge sealift capacity needed by the government in time of war.

LPD-17 - Latest Amphibious Ship

LBP - Length Between Perpendiculars - usually the length of the ship at the waterline

LM-6000 - Advanced gas turbine engine developed by General Electric

LOA - Length Over All - Total length of the ship

LSI - Lean Ship Initiative

MARITECH - Marine Systems Technology

Margin - Reserve for future growth

MHI - Massachusetts Heavy Industries

MILSPEC DH-36 - High Tensile Strength Steel Plate

MILSPEC - Military Specifications

Molecules - System Dynamics Building Blocks generated by Jim Hines for Vensim and 15.875

MTSSTD - Mid-Term Sealift Ship Technology Development Program

MW - Mega Watt

NASSCO - National Steel and Shipbuilding Company

NAVSEA - Naval Sea Systems Command

NAVSHPPSO - NAVSEA Shipbuilding Support Office

NDF - National Defense Features

No Touch Labor - Not involved with structural steel of outfitting of ship, e.g. cleaning people

NSRP - National Shipbuilding Research Program

OPA 90 - Oil Pollution Act of 1990

Opti Nest - Automatic plate marking and cutting CAD/CAM system

Outfitting - The installation of all systems in the structural steel framework of a ship This includes piping, electrical cables, furniture, machinery, and other items

Panels - Plates of steel which make up the sides, bottom and decks of the ship

PERT - Probabilistic Evaluation and Review Technique

PO2 - The On Block portion of the BIW construction sequence

PWBS - Product Work Breakdown Structure

QA - Quality Assurance

RRF - Ready Reserve Force

RO/RO - Roll On/Roll Off ship - Can carry cars, trucks or tracked vehicles. Loaded and unloaded without the use of cranes.

SA'AR - Corvette sized combatant built by Ingalls for Israeli Navy.

SC-21 - Next combatant ship program after DDG-51

Shipbuild - New project planning and progress tracking software which will use some elements of System Dynamics

Ship Production Model - A virtual representation of a particular ship being built at a shipyard

SHP - Ship Horse Power

SOCV@MIT - 13.414 Year Long Design Project Team

Stealth - Ability to evade radar

SUPSHIP - Supervisor of Shipbuilding

Strakes

Strategic Sealift - Shipping which provides heavy lift of Department of Defense Equipment from CONUS to the area required

System Dynamics - Methodology used to examine complex problems with non linear relationships and feedback

TEU - Twenty foot Equivalent Unit

Title XI - Loan guarantees meant to stimulate shipbuilding in this country

TOC - Total Ownership Costs

Unit - The smallest level of sub assembly in the process. Includes entire system of machinery like fire pumps. Units can be tested for proper operation at the shop level

USCG - United States Coast Guard

Vensim - System Dynamics modeling software

Waterjet - Method of Propulsion much like a jet engine. Ship is propelled by a jet of water instead of a propeller.

WBD - Weeks Before Delivery

WIP - Work In Progress

WT, T, W-T -

Zones - Defines what functions are carried out in this portion of the ship e.g. Machinery, Living, Storage

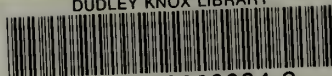
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